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MTR-1205 VOLUME II

TECHNICAL REVIEW OF THE MCC-H AUGMENTATION II DESIGN APPROACH

22 MAY 1967

REVIEW AND DESIGN PROCESSES: SUPPORTING INFORMATION

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Author: D. I. Buckley, A. S. Goldstein, E. S. Herndon, J. S. Quilty

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Page 1 of 160 Pages

ABSTRACT

The material presented in this volume was developed to support a technical review of the MSC proposed Augmentation II design approaches for MCC-H systems. However, the appendices are essentially self contained descriptions of a design review and design synthesis process. This volume can be read and used independently from the review itself which is documented in Volume I of this MTR.

The techniques presented in Appendix A for estimating computer loading and computer hour requirements for the Real Time Computer Complex are of more general interest and application than this current review of Augmentation II designs. The same or very similar techniques could be applied to design of the other data handling systems within the MCC-H. Also, the results of the independent design synthesis for the RTCC (Appendix B) are useful in understanding relationships between operational requirements and system design features. In particular, the impact on system design of different requirements levels is illustrated.

Appendix A, "Review Procedure and Associated Tools/Techniques," describes both a procedure for reviewing MCC-H augmentation proposals and a set of supporting information pertinent to application of this review procedure. The two primary system sizing tools, the RTCC loading and computer hour estimators, are described. A tabulation of post-Apollo requirements in a form considered particularly meaningful for review purposes is also provided.

Appendix B, "Design Process and Results," describes an independent design effort whose primary objective is the determination of RTCC system costs for various system organization alternatives and for various alternative statements of post-Apollo requirements. The general approach to the design problem is described as well as the detailed application of a specially-tailored design process. Design results are summarized and discussed. Note that Appendices B.1 - B.5 have been intentionally constructed such that reading of B.1 and B.5 only will generally suffice for those whose interest does not extend to the detailed development of design results.

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APPENDIX A

REVIEW PROCEDURE

AND

ASSOCIATED TOOLS/TECHNIQUES

APPENDIX A.1

GENERAL PROCEDURES USED IN THE REVIEW

Review of the design approaches developed by the Augmentation working groups at MSC is essentially limited to consideration of the data handling and display/control system design problems. This limitation in scope was jointly agreed upon by the Augmentation II Steering Committee chairman and MITRE management in recognition of the limited manpower MITRE could apply to the task, the particular match of the task to the talents available, and the most critical issues in the Augmentation II design study.

The review in general will consist of comparing the capabilitites of the various system designs with the operational and system requirements as stated in or derived from SR 500. The review process has been arbitrarily divided into four parts and each design alternative will be treated as follows:

1. An estimate of the loading on each operational RTCC central processor will be made to determine if it can meet the worst case real-time processing load imposed by simultaneous flight control requirements. (A similar estimation of CCATS loading would also be desirable but data was not available at the time of the review.)

2. A comparison will be made between the number of computer hours per month required to support the flight schedule and the number of computer hours per month available.

3. A review will be made to determine if other system requirements such as number of TV channels, provision of new control areas, and the like are satisfied.

4. System capabilities will be considered in terms of a set of selection criteria such as cost, growth capability, ease of reconfiguration, etc.

This review procedure is depicted in Figure A.1-1 and the paragraphs which follow provide a more detailed explanation of the four step review procedure. In the flow diagram of Figure A.1-1, the four steps are separated by the three decision points. A total of six tools have been developed to support the review process with the first three of these (comprising the first review step) leading to the evaluation of the capability of the system to meet the processing load requirements. These design review tools and their use in the review are discussed in the following paragraphs.

STEP I - APPLICATION OF LOADING REQUIREMENTS

MCC-H Data Handling Functional Diagram

The MCC-H Data Handling Functions are shown on a large data flow chart in Appendix A.2 which indicates all of the functions to be performed in the CCATS, RTCC and Display Systems. The first step associated with the design review will be to express the design alternative in terms of the functions performed by each computer in the system.

For example, a data handling alternative may call for two RTCC computers to be used in support of all operations with one being devoted to telemetry input processing and the processing of all displays related to telemetry and the other devoted to the remaining trajectory, mission planning and command processing, and their associated displays.

Mission Schedule Worst Case Vehicle Combinations

The schedule of flights to be controlled by the MCC-H imposes requirements for multiple mission support. Through review of SR 500 model and conversations with FCD personnel, several different "worst case" control situations have been constructed. These are developed in Appendix A.2. These "worst case" situations indicate the number and types of vehicles for which the system must provide telemetry, tracking, command and other system functions. Using the worst case situations and the allocation of functions for the design alternative being considered, the number and types of vehicles being handled by each computer in the configuration can be found. For example, if an alternative calls for all telemetry processing to be done in one computer one would simply take the number and types of telemetry sources in the worst case situation and assign the telemetry processing tasks for all of them to that computer.

% CPU Loads on Per Vehicle Basis

For each function performed by a system computer a load is imposed on the Central Processing Unit by the processing associated with each vehicle. This load is expressed in terms of the percentage of available Central Processing Unit time, (% CPU). These loads vary with vehicle type and in many cases with mission phase. Appendix A.3 presents a model which will permit estimation of these "per vehicle loads" for each system function. Then using the numbers and types of vehicles found in the analysis of the SR 500 schedule models above, an estimate of the total load on each computer will be found. If the estimated system load is less than the computing capacity of the proposed system design, the alternative will be considered to have met the loading requirements.

STEP II - APPLICATION OF COMPUTER HOUR REQUIREMENTS

Estimates of computer hour requirements are developed in Appendix A.4 for all uses of RTCC computers except direct mission support, for flight densities from seven to thirteen flights per year. The uses of RTCC computers include the development of programs for Mission, GSSC ORACT, RTOS and others. Also included are the use of the computers for Simulations, SIM Checkouts, Pad tests, administrative and engineering overhead, and the like. Estimates of direct mission support computer hours are a function of the system organization and the densities and durations of the mission involved; these estimates are presented in Appendix A.2. The number of computer hours provided by the system alternative will be compared against the estimates from the two appendices to determine if sufficient computer hours are provided.

STEP III - APPLICATION OF OTHER REQUIREMENTS

The "other requirements" indicated in the review procedure are developed in detail in Appendix A.2. This set of requirements includes such items as numbers of TV channels, provision of new control areas, and the like. While some of these, such as dynamic standby requirements, contribute directly to the evaluation of loading and computer hour requirements, others, such as the provision of handover from a MOCR to a SOCR, do not. This checklist of requirements taken from SR 500 provides a means of covering all requirements which were not considered explicitly in the previous steps of the review. All design alternatives satisfying these requirements are compared in the next step.

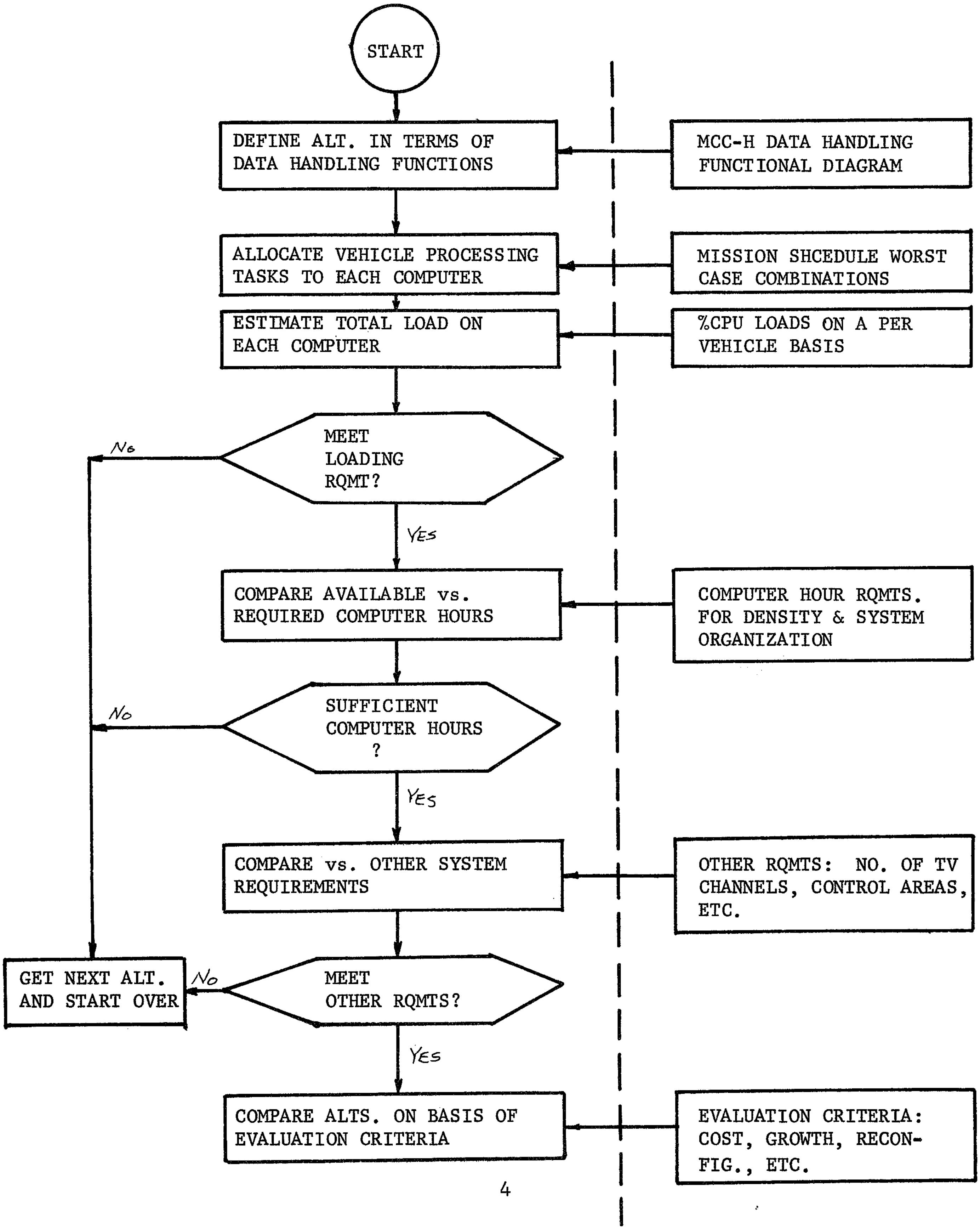
STEP IV - EVALUATION CRITERIA

The last tool developed in Appendix A.5 is a set of evaluation criteria for comparing various alternatives which meet the requirements. These criteria include cost, growth potential, flexibility and other such characteristics.

The application of these criteria to system design alternatives which meet the basic requirements provides a basis for selecting between the system designs. While some of the criteria such as cost and growth potential can be expressed in quantitative terms (e.g., dollars and spare Central Processor Capacity), others such as ease of reconfiguration or ease of testing will be applied in a qualitative sense.

Figure A.1-1

REVIEW PROCEDURE
EVALUATION TOOLS & CRITERIA



APPENDIX A.2

POST-APOLLO MCC-H REQUIREMENTS

INTRODUCTION

In support of the review procedure described in Appendix A.1, this appendix states what are considered to be the most significant requirements from an Augmentation II design viewpoint. In particular, those requirements which affect system organization and sizing have been emphasized. Different requirements influence system design at different levels of design detail. As a result, the level of descriptive detail for the design alternatives to be reviewed will determine which of the requirements stated in this appendix may be usefully introduced into the review process.

The designs subjected to review in this document are intended to satisfy post-Apollo requirements as stated in SR 500.* The requirements tabulated below, therefore, have been derived from SR 500 and have, in addition, been informally coordinated with Flight Control Division personnel unless otherwise noted. MITRE, however, is responsible for the selection of those requirements considered most significant and for the particular translation of SR 500 requirements into system requirement statements.

For those requirements which are dependent upon the particular SR 500 mission model being considered, two distinct derivations have been provided; one for the SR 500 Prime Model and one for the SR 500 Interim Model 3. The Prime Model represents the ultimate goal of the Augmentation II design effort. Interim Model 3 provides what might be considered a realistic set of minimal operational requirements which will have to be satisfied by one of the incremental augmentation steps leading toward the Prime Model support configuration. The Prime and Interim model requirements represent two points in a possible spectrum of operational requirements which the MCC-H could be called upon to support. Developing design alternatives for different sets of operational requirements may permit one to identify the sensitivity of system design to certain mission model characteristics. Such a sensitivity investigation as applicable to the RTCC configuration in particular is discussed in Appendices B.1 through B.5.

REQUIREMENTS STRUCTURE

With the exception of requirements related only to computer hour demands upon the system, requirements are tabulated below under the general heading of "Mission Support." As used herein, "Mission Support" includes support for both actual missions (commencing with launch) and for the Simulation Operational Computer (SOC) portion of simulated missions (or its equivalent; GSSC not included) based on the groundrule that the simulation system will look like the "real world" to the post-Apollo equivalent of CCATS, the RTCC, and the Display/Control (D/C) system. "Functional Requirements" and "Performance

* August 29 issue thereof as expanded by November 1 memorandum and as reissued in draft form as SR 500, Revision 1.

Requirements" appear as subheadings under "Mission Support" with the former oriented toward the question of what must be done and the latter toward the questions of how much, how rapidly and how reliably. "Performance Requirements," therefore, are generally quantitative.

Requirements impacting upon computer hour demands are treated as a special case because these, unlike the above, are not constrained to a mission time context. Computer hour demands may be viewed only as a totality in a long-term context which includes non-mission as well as mission time and which encompasses a wide variety of activities preparatory to a mission as well as the mission itself.

MISSION SUPPORT REQUIREMENTS

Functional Requirements

Functions to be performed within the MCC-H data processing and display complex are represented at a system level by the attached block diagram, "MCC-H Data Handling Functions," Figure A.2-1.* This diagram, however, does not reflect certain system design requirements of a functional nature which are either derivative from an understanding of the Flight Controller concept of operation or are stated directly in SR 500. These must be "superimposed" upon the block diagram. Recognizing the general SR 500 requirement for up to four concurrent operations (e.g., two missions and two simulations) supported by four independent operational areas (two MOCR's and two SOCR's), additional requirements are:

Display Related

The system organization must permit parallel access by all operational FC elements associated with a single floor (MOCR, SOCR, SSR's, EAR, SPAN, "½" of the Resource Control Facility) to all D/TV displays related to any mission activities being supported by that floor.

All duplicated operational FC elements require access to D/TV display data related only to mission activity on the floor on which they are located.

Non-duplicated operational elements require access to D/TV display data relative to the activities of either or both floors. These are the Recovery Control Room, the Weather Room, and the OMR.

All D/TV display positions require the capability to request a display format not being otherwise viewed with the following exceptions: the SPAN, the EAR's, and the Weather Room. These require a "latchup" or "slaving" capability only.

The capability must exist during a mission period (may involve more than one mission in cases of overlap) to manually modify D/TV formats within

---

* Dotted lines in the attached diagram indicate the division of functions between MCC-H systems and subsystems for the present version of the Apollo System. Exception: Digital TV is included because its implementation for at least a portion of the total TV system has already been scheduled.

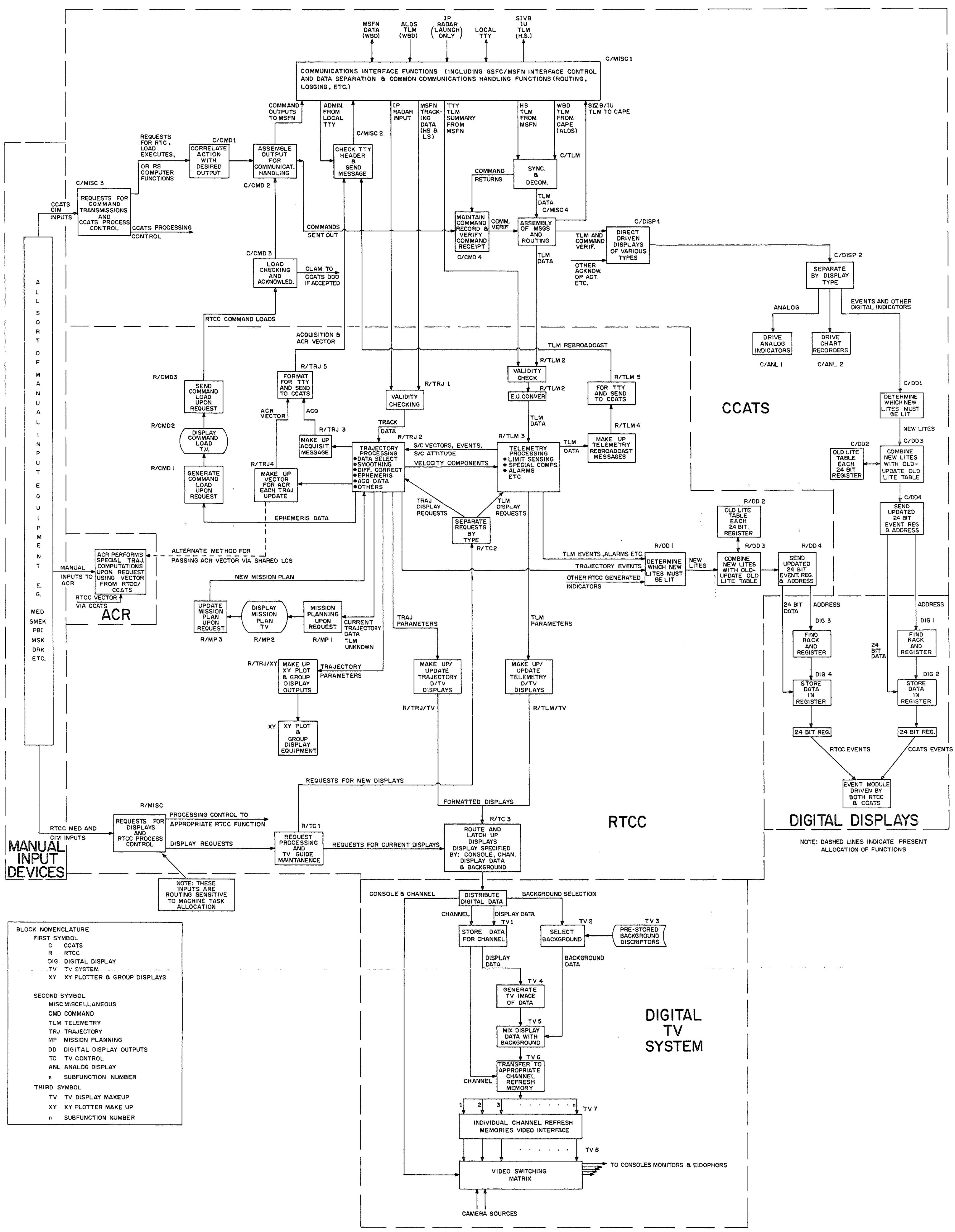


Fig. A.2-1

MCC-H DATA HANDLING FUNCTIONS

bounds which have been well specified from a software standpoint prior to the mission; i.e., real-time D/TV display format modification will be constrained by pre-defined options.

The capability must exist to modify, during a mission period, display distribution of event/analog/digital data relative to FC console modules. Such modification will be limited to changes which may be accomplished by software reconfiguration alone. Again, the concept of pre-defined options is applicable.

System organization must permit reconfiguration of digital/event/analog (not D/TV) display data distribution for a MOCR or SOCR simultaneous with mission conduct from the other control area on the same floor.

Processing-Related

The system organization must provide the same processing/display support for a SOCR as for a MOCR; i.e., system designs based on differing levels of capability between a SOCR and a MOCR are unacceptable.

Although TLM/TRAJ processing functions during noncritical mission phases (see SR 500) need not be performed continuously and on-line in response to all associated network data, immediate call-up of such functions must be facilitated in support of contingency situations. By the same token, mission planning and command load generation functions need not be on-line, but must be available on a rapid call-up basis.

Mission Phase-Related

Support need be provided for a maximum of one critical phase or two simultaneous semicritical phases per floor. (See SR 500 for definitions of critical, semicritical and noncritical.)

Unique SIM Considerations

The above functional requirements statements do not distinguish between simulated and actual missions. SIM requirements are considered to be adequately covered by the above with the exception that the following additional statement must be included:

> System organization must permit conduct of mission simulation from either the MOCR or the SOCR on a given floor concurrent with actual mission conduct from the other mission control area on the same floor. (Note: SR S-500 is the source of this requirement.)

Performance Requirements

Requirements Related to Instantaneous Loading/System Sizing

Two requirements areas have been selected as most significant to system loading/sizing at the design approach level: the worst-case combinations of vehicles (numbers and types) to be supported simultaneously and the telemetry (TLM) and trajectory (TRJ) data requirements associated with these combinations; the number of display channels required per floor.

Vehicle Support Situations and Associated Data Requirements:

Worst-case vehicle support situations have been formulated with emphasis on the "% of CPU Time Used" as the most significant single aspect of system loading/sizing. A variety of support situations have been developed as follows:

> Worst-case loads for a single mission to permit sizing of mission-oriented computing elements.
>
> Worst-case loads which both do and do not include a launch to permit sizing of configurations which do and do not consider launch as a special case.
>
> Worst-case loads with and without simulations to permit sizing for different combinations of actual and simulated missions.

Table A.2-I presents, for both the Prime Model and Interim Model 3, the worst-case vehicle support situations of interest and the assumptions used to derive these from SR 500. As an example, reference Table A.2-IA for requirements derivative from the SR 500 Prime Model. The leftmost column entries define a number of multiple-mission cases based on the number of concurrent operations (combinations of actual missions and simulations) and the with and the without launch distinction noted previously. Multiple-mission cases are of interest when sizing any configuration involving other than standalone computing elements. In addition, a single mission case is presented in support of loading estimation for standalone elements. For each case, the five "vehicles to be supported" columns specifically identify the vehicle support requirements. (See the key associated with Table A.2-I for a description of the conventions employed.) The first four columns present a breakdown of the total number of vehicles to be supported into categories defined primarily by mission phase and/or mission type with lunar surface vehicles treated as a special case. The fifth column summarizes each case from both a telemetry and a trajectory viewpoint.

Note that certain of the assumptions specifically related to simulations constrain the level of actual mission activity which may be concurrent with simulation activity on the same floor. Although FCD Simulation Branch personnel have indicated a willingness to accept certain such constraints in practice, no such constraints appear in SR S-500. (The constraints in Table A.2-I appear to imply full simulation capability for a minimum of 22 days prior to the next mission on a given floor.)

Table A.2-II presents, for each case in Tables A.2-IA and A.2-IB, the tracking requirements (in terms of the number of vehicles tracked at both high and low speeds and whether or not launch tracking is included), the telemetry processing requirements (in terms of the numbers and types of formats received), and the effective data rate required between GSFC and MCC-H. Assumptions pertinent to the derivation of these data requirements are presented as well.

The requirements information presented in Tables A.2-I and A.2-II may, as indicated generally in Appendix A.1, be employed for review purposes as follows:

Table A.2-I

Worst-Case Simultaneous Vehicle Support Requirements

ASSUMPTIONS

General

No dual launches within the same 24 hour period except in the case of 90 minute spearation between rendezvous-related earth orbit flights.

Pad support will not be required concurrent with worst-case simultaneous vehicle support situations except in the case of earth orbit flights whose launches are separated by only 90 minutes. In this case, pad support of the second flight is required while the first flight is being launched and until launch of this second flight. (Implications: pad support will generally be scheduled as coincident with low levels of inflight activity or required monitoring of only a subset of the total complement of inflight vehicles.)

Lunar injection will be accomplished within 12 hours after launch of a lunar mission.

Docking between earth orbital flights such as the second and third flights in an earth orbit "large" mission will occur within 24 hours after launch of the third flight.

For purposes of telemetry monitoring, an S-IVB vehicle maintained beyond insertion for earth orbital operations will constitute an EM.

Regardless of the number and type of unmanned lunar surface vehicles, only one such vehicle need be monitored concurrent with the worst-case simultaneous support situations for inflight vehicles. This single vehicle will be considered as an EM. (Note: this assumption is intended to be consistent with the "limited support" philosophy recognized in SR 500, Revision 1.)

Specifically Related to Simulations

No simulations will be conducted during an actual launch.

In the case of two simultaneous simulations, only one simulated launch may be included.

Simulations may be conducted on the lunar floor only when live lunar support is limited to the monitoring of unmanned lunar surface vehicles.

Simulations may be conducted on the earth orbit floor only when no more than two earth orbit flights are active and when these two flights are in non-launch, non-reentry phases. (Implication: may conduct simulations prior to the third flight in an earth orbit "large" mission while monitoring the vehicles remaining from the first two flights. May not conduct simulations after launch of the third flight until end of the "large" mission; the next earth orbit mission occurs long enough after reentry to adequately support simulations within such a constraint.)

Table A.2-I (Continued)

A simulation on one floor may be conducted concurrent with any non-launch live operation on the other floor.

Launch simulations will involve only the following vehicles:

For 200 Series: S-I, S-IVB, CSM (or LM) (EM Passive)
For 500 Series: S-I, S-II, S-IVB, CSM (LM & EM Passive)

Non-launch simulations will involve trainers as well as GSSC math models to achieve the following maximum vehicle configurations:

For Earth Orbit Missions: CSM, LM, 2 EM's
For Lunar Missions: CSM, LM, EM

KEY:

A B C	-	Vehicles A, B, and C are docked or combined and, therefore, may be considered as a single vehicle (or target) from a tracking viewpoint.
X Y	-	Vehicle combination "X" is rendezvousing with vehicle combination "Y."
H.S.	-	High-Speed
L.S.	-	Low-Speed
LCH	-	Launch
W/	-	With
W/O	-	Without
TLM	-	Telemetry
TRJ	-	Trajectory

TABLE A.2-IA

SIMULTANEOUS VEHICLE SUPPORT REQUIREMENTS;
Worst-Case Situations from SR 500 Prime Model

CASES OF INTEREST	In Launch	Inflight E.O. Vehicles	Inflight Lunar Vehicles	Lunar Surface Vehicles	Total No. of Vehicles
	VEHICLES TO BE SUPPORTED				
For Live Missions Only (Up to two) • All missions w/ a launch included	SI SII SIVB LM CSM EM 500	CSM LM EM EM CSM EM	-	EM	TLM 13 TRJ 3
• All missions w/o a launch included	-	CSM LM EM EM CSM EM	CSM EM LM (Lunar Descent)	EM	TLM 10 TRJ 4
• Any single mission (may be multi-flight)	SI SIVB CSM EM 200	CSM LM EM EM (Docked)	-	-	TLM 8 TRJ 2
For Live + 1 SIM Mission (Total of up to 3) • w/ a simulated launch	SI SIVB CSM SIM 200	CSM LM EM EM live	CSM LM EM live	EM_{live}	TLM 11 TRJ 3
• w/o a simulated launch	-	LM CSM EM EM live LM EM CSM EM SIM rendez	CSM EM live LM (Lunar Descent)	EM_{live}	TLM 12 TRJ 5
For Live + 2 SIM Missions (Total of up to 4) • w/ one simulated launch	SI SII SIVB CSM SIM 500	LM CSM EM EM live LM EM CSM EM SIM	-	EM_{live}	TLM 13 TRJ 4
• w/o a simulated launch	-	LM CSM EM EM live LM EM CSM EM SIM	LM CSM EM live	EM_{live}	TLM 12 TRJ 4

TABLE A.2-IB

SIMULTANEOUS VEHICLE SUPPORT REQUIREMENTS;
Worst-Case Situations from SR 500 Interim Model 3

CASES OF INTEREST	VEHICLES TO BE SUPPORTED In Launch	Inflight E.O. Vehicles	Inflight Lunar Vehicles	Lunar Surface Vehicles	Total No. of Vehicles
<u>For Live Missions Only</u> (Up to two) •All missions w/ a launch included	SI SIVB CSM EM 200	CSM LM EM EM		EM	<u>TLM</u> 9 <u>TRJ</u> 2
•All missions w/o a launch included	-	CSM LM EM EM CSM EM		EM	<u>TLM</u> 7 <u>TRJ</u> 2
•Any single mission (may be multi-flight)	SI SIVB CSM EM 200	CSM LM EM EM	Note: Same as for Prime model.		<u>TLM</u> 8 <u>TRJ</u> 2
<u>For Live + 1 SIM Mission</u> (Total of up to 3) •w/ a simulated launch	SI SIVB CSM SIM 200	CSM LM EM EM live		EM live	<u>TLM</u> 8 <u>TRJ</u> 2
•w/o a simulated launch	—	CSM LM EM EM live CSM LM EM EM SIM RENDEZ.		EM live	<u>TLM</u> 9 <u>TRJ</u> 3
<u>For Live + 2 SIM Missions</u> (Total of up to 4) •w/ one simulated launch •w/o a simulated launch	Not applicable to Interim Model 3 - launch intervals preclude need for more than two concurrent operations. (See previous assumption regarding pad support.)				

Vehicle support requirements from Table A.2-I plus the associated tracking requirements from Table A.2-II may be combined with the RTCC loading estimators developed in Appendix A.3 to produce % CPU time used figures for the RTCC (where the CPU is a Model 360/75).

Table A.2-II TLM format processing requirements may be combined with estimators for % 494 CPU time used per format (if such estimators are available) to produce % CPU time used estimate for CCATS (TLM real-time load considered primary).

Table A.2-II GSFC/MCC-H data rate information may be used to critique the adequacy of communications interface provisions.

Display Channel Requirements:

Approximately 60 D/TV channels per floor.

Response Time/Reconfiguration Time Requirements

Reconfiguration Requirements During A Mission: The system must respond "within minutes" to a request to modify D/TV formats or event/analog/digital data routing. (Modifications within pre-defined options as discussed under "Functional Requirements.")

If the system is being operated in a mode in which only a subset of the total number of display formats is available on an immediate call-up basis, a return to operation with all formats available must be accomplished within fifteen minutes upon request.

Display Response Time Requirement: Although response time is considered significant by Flight Controller personnel, no quantitative version of such a requirement exists in formal post-Apollo requirements documentation. This heading is included herein only to recognize the significance of such a requirement.

Reliability and Related Requirements

Quantitative availability and/or reliability requirements have not been formalized. Recovery time, however, has been considered particularly significant. Required recovery time by type of mission phase is as follows:

Phase Type	Recovery Time
Critical	Immediate (Dynamic Standby)
Semicritical	30 Minutes
Noncritical	2 Hours

REQUIREMENTS RELATED TO COMPUTER HOURS

Two (2) characteristics of the SR 500 mission models significantly affect the total computer hour demands on the MCC-H Systems. Because many activities requiring computer time - program development and checkout, for instance - may be viewed on a per mission or per flight basis, flight density (expressed in

Table A.2-II

Tracking/Telemetry Data Requirements
Associated with Table I Support Cases

ASSUMPTIONS (Selected to generate worst-case data requirements)

Tracking-Related

All vehicles which are distinct from a tracking viewpoint ("tracked vehicles") are being tracked simultaneously.

All vehicles not in launch phase result either in low-speed tracking data inputs at a rate of one vector every six seconds or in high-speed tracking data inputs at a rate of ten vectors per second.

Whenever launch activity on the same floor is not taking place, a critical phase for a single-tracked vehicle is in progress and involves a burn of sufficient duration to warrant transmission of high-speed tracking data. All other tracked vehicles monitored on the same floor result in low-speed tracking inputs.

Telemetry-Related

All vehicles are within ground coverage simultaneously for TLM monitoring purposes.

Any single remote site may transmit a maximum of three high-speed TLM formats to the MCC-H simultaneously.

Whenever more than one in-flight vehicle is being monitored by the same site, each vehicle will result in a separate 2.4 kbps format for transmission to the MCC-H.

Vehicles on the lunar surface will be monitored by separate 2.4 kbps formats.

GSFC/MCC-H Data Rate-Related

Each tracking data vector will be received from GSFC as a single 600-bit block. As a result, high-speed tracking data may be considered as requiring six kbps of GSFC/MCC-H bandwidth. (10 vectors/sec. X 600 bits/vector = 6,000 bits/sec.) Low speed tracking data may be considered to require negligible bandwidth.

Each high-speed telemetry format (2.4 kbps from remote site to a switching center) incurs approximately a 25% "communications handling overhead." Each such format, therefore, may be considered to require three kbps of GSFC/MCC-H bandwidth.

TABLE A.2-II

TRACKING/TELEMETRY DATA REQUIREMENTS
ASSOCIATED WITH TABLE I "CASES OF INTEREST"

TABLE A.2-I CASE	TRACKING REQUIREMENTS			TLM FORMAT PROCESS		GSFC/MCC-H Data Rate* (TLM & TRK)
	Launch Trking	# Vehicles Tracked at H. S. Rates	# Vehicles Tracked at L.S. Rates	Launch TLM (ALDS)	# of H.S. Formats Received	
<u>Prime Model</u>						
For Live Missions Only,						
All missions w/ launch	yes	1	1	yes	6	+24 Kbps
All missions w/o launch	no	2	2	no	9	39 Kbps
Any single mission	yes	1	-	yes	3	15 Kbps
For LIVE + 1 SIM						
w/ a simulated launch	yes	2	-	yes	7	33 Kbps
w/o a simulated launch	no	2	2	no	11	27 Kbps
For LIVE + 2 SIM's						
w/ a simulated launch	yes	1	2	yes	8	12 Kbps
w/o a simulated launch	no	2	2	no	11	27 Kbps
<u>Interim Model 3</u>						
For LIVE Missions Only						
All missions w/ launch	yes	1	-	yes	4	18 Kbps
All missions w/o launch	no	1	1	no	6	24 Kbps
Any single mission	yes	1	-	yes	3	15 Kbps
For LIVE + 1 SIM						
w/ a simulated launch	yes	1	-	yes	4	18 Kbps
w/o a simulated launch	no	2	1	no	8	18 Kbps
For LIVE + 2 SIM's						
w/ a simulated launch	Not applicable - See Table A.2-IB					
w/o a simulated launch						

* Live Data Only. SIM data not additive because of interfaces unique to SIM. Also, Launch component not included.

flights per year) is of primary importance. Because computers supporting actual missions are not available for other purposes, mission/flight duration must be considered in terms of the resulting computer hour utilization. Quantification of these characteristics for each of the two SR 500 models of interest is discussed below.

Flight Density

A density of eight (8) flights/year is specified for both the Prime Model and Interim Model 3.

Mission/Flight Duration

Computer hour demands related to mission/flight duration may be expressed as the number of computer hours per month required for support of actual missions. Assuming a mission-oriented computer configuration, this value may be calculated as the sum of all mission durations (not the sum of all flight durations) within the one year period represented by each model plus some number of hours to account for dynamic standby operation during critical phases. For purposes of this analysis, 36 hours per flight within a mission has been assumed to cover periods of dynamic standby operation based on 24 hours/flight for launch and final pad support plus 12 hours/flight for non-launch critical phases. Result:

> 444 computer hours/mo (avg) to support either the Prime Model or Interim Model 3 with a mission-oriented configuration

An additional set of values, however, must be developed to describe analogous requirements for a functionally-oriented configuration. In this case, mission overlap tends to reduce computer hour demands because functional elements are multi-mission in nature and, therefore, the computer hour utilization of a functional configuration is insensitive to the number of missions being supported at a given time. A computer hour/mo value for each model must be calculated as the sum of all hours during which any actual mission is being supported plus a number of dynamic standby hours as per the previous assumptions. Note that the resulting values apply to each functional element in a particular functionally-oriented configuration; these values must be multiplied by the number of functional elements to achieve a total computer hour figure. Results:

> For the Prime Model, 264 hrs/mo per functional element are required.
>
> For Interim Model 3, 384 hrs/mo per functional element are required.

These "per functional element" figures include computer hours devoted to launch support. On this basis, it may be shown that these figures adequately cover any computer hours on a specially-allocated launch support element for functional configurations which treat launch as a special case. As a result, total direct support computer hour requirements may be achieved by multiplying these figures by the number of functional elements regardless of whether or not launch is treated as a special case.

Use of the Above

Estimation of total RTCC computer hour requirements is achieved in two steps:

> Combining the flight density requirements with the computer hour estimators developed in Appendix A.4 to yield total computer hour requirements exclusive only of hours for actual mission support. Appendix A.4 estimators reflect both computer hour requirements which are sensitive to flight density and requirements viewed as constants on a monthly basis. Because ACR computations are executed in a job shop environment, ACR requirements are considered, for purposes of this review, to be simply a component of the total computer hour requirements. As such, ACR computer hours are treated in Appendix A.4.
>
> Adding the actual mission support hours as per the above.

APPENDIX A.3

AUGMENTATION II RTCC LOADING ESTIMATION

INTRODUCTION

This paper presents a method for estimating the RTCC loading during the launch, major burn, and orbit phase periods of post-Apollo missions using IBM System 360/75 computers.

The data presented has been taken from both the inputs to the GPSS model for Mission 207/208 and from the results of the GPSS runs. It should be noted at the outset that the data presented in this report is specifically tailored to answer the loading questions associated with the Augmentation II data handling problem. Only RTCC loading is addressed in this report.

This paper is divided into three sections. The first section explains the general technique used in producing the loading estimators. The second section presents detailed tables for the various processors in the system and indicates how they should be used in estimating loading for a given configuration. The third section presents these same results in a condensed form which is more immediately useful in applying the numbers.

GENERAL TECHNIQUE USED IN DEVELOPING THE LOADING ESTIMATORS

Loading Components and Loading Situations

RTCC system loading in this report will be expressed as the percentage of available central processing unit time which is used to perform a given processing task; this will be abbreviated "% CPU." The system loading is made up of two components: the applications programs loading and the Real Time Operating System (RTOS) loading. The applications programs perform all of the mission-oriented computations. The RTOS performs all of the executive services required for I/O control, program linkages, storage management, etc.

The RTCC computers must be able to support two types of applications processing loads. For want of better terminology, these will be referred to as real-time processing loads and event-dependent processing loads.

The real-time processing loads are those loads for which the processing must be completed within a fixed processing cycle. Examples of this type of processing include telemetry input processing, trajectory input processing, routine updating of digital and D/TV displays and the handling of routine manual inputs.

The event-dependent processing loads are those loads for which processing is not tied to a fixed processing cycle but rather to a manual request for trajectory-related processing or an event which occurs in the trajectory. Generally the trajectory event-dependent load can be deferred by giving it a lower priority in the system. The result of the lower priority is that the response to the request for processing may not be received until several seconds have elapsed. Examples of this type of processing are mission planning, ephemeris update, hold phase processing, and the orbit processing which occurs after station passes. The general characteristics of the processors which perform these computations are that they are not continuously used, but when they are used, they tend to saturate the computer until the computer can "work off" the load. During the interval in which the computer is working off the event-dependent processing load, it must also accomplish the processing associated with any real-time demands which may be present.

Two different types of loading situations can occur: the load imposed in a given processing interval can demand less than 100% of the CPU, or the load imposed by some of the event-dependent processors can cause the system to saturate for a period of time until the system can "work off" the load. The system is designed to handle both types of loading situations. Processing during the powered flight portion of the launch phase is an example of the former type of loading situation in which it is currently desirable to process all of the incoming telemetry and trajectory data without exceeding 70% CPU loading. (Seventy percent has been chosen to provide a 30% margin of additional computing capacity for contingencies.) Processing during the hold portion of the launch phase is an example of the latter type of loading situation in which it is desirable to process all of the real-time telemetry and trajectory data and to use the remaining capacity to perform the GO/NO GO trajectory computations. A criterion for successful event-dependent computations, although not explicitly stated in operational requirements, might be that the system process all of the real-time data and "work off" the event-dependent load within a specified response time.

In summary, the RTCC computers must accommodate two types of applications loads, real-time and event-dependent. Furthermore, two loading situations can be expected: a saturated and a non-saturated condition. The saturated condition can be tolerated if the following conditions are met: first, the computer must be able to keep up with the real-time loads; second, there must be sufficient capacity remaining after satisfying the real-time demands to process event-dependent loads in a "timely manner."

In this study loading estimators for individual processors will be developed for the real-time applications loads only. Capacity for event-dependent loads must be provided by reserving an appropriate margin to satisfy event-dependent processing requirements. All of the heavy event-dependent processing loads are associated with trajectory related computations. Consequently the margin provided in the computers should be sensitive to the amount of event-dependent trajectory computations to be supported by the computer. In a computer dedicated to telemetry processing only, naturally, no margin would be required for these event-dependent trajectory computations. In computers which provide event-dependent processing, the amount of margin reserved should be a function of the number of trajectories maintained. A computer which supports the trajectory processing for a single mission should probably have a 30% margin reserved. One which provides trajectory computations for more than one mission should probably have a margin of 40% to 50% reserved. Firm guidelines for margins are not intended by these examples. The decision on what margin should be allowed can best be made by considering each individual design alternative.

The % CPU Loading Estimators

For the 360/75 System, the % CPU required by the applications programs is a function of the amount of time required by each applications program and the number of times the program is used during the sample interval. The % CPU required by RTOS to service the applications programs can be approximated by two components: one component is fixed by the demands of the applications programs; the other component varies with the relative size of main core. This variable portion reflects the additional work required of RTOS for purging* main core when the total size of programs, tables and working areas required in main core over the sample interval exceeds the available main core storage.

The variable RTOS load due to purging has not come into play in the launch phase (usually the most stringent real-time loading condition) in the recent past because there has been enough main core available to accommodate virtually all of the programs required during launch. With the larger core available on the 360/75 this condition can be expected to continue. Throughout this paper we will neglect the portion of CPU loading which is attributable to purging main core. Admittedly we are begging the question at this point with regard to purging main core for other than launch phase, but it is generally the case that if the computer will handle the launch load then it will have some spare capacity during other phases to perform the purge if it is required.

In summary for a given applications program the % CPU will be estimated by considering the running time of the applications program, the RTOS running time required to service its demands, and the number of times during the sample interval that the applications program is run. This results in the following expression for estimating loading:

$$\% \text{ CPU}_i = \frac{n_i}{t_t} (t_i + t_{ri}) \times 100$$

where

$\% \text{ CPU}_i$ = total % CPU due to processor i

n_i = number of uses for processor i in the sample interval

t_t = total amount of time in the sample interval in seconds

t_i = the running time for processor i in seconds

t_{ri} = the running time required by RTOS to service the demands of processor i

Note that the expression $\frac{n_i}{t_t}$ is the rate of using processor i over the interval. This simplifies the expression to the following:

$$\% \text{ CPU}_i = r_i (t_i + t_{ri}) \times 100$$

where r_i = rate of using processor i in uses per second.

The % CPU for each processor is thus a function of three quantities:

---

* Purge is an RTOS task which removes programs and tables from main core to free space in core for other programs or tables.

the rate of usage, the processor running time, and the supporting RTOS running time. The first two quantities are taken from the definition of and inputs to the GPSS model. The supporting RTOS time is taken from an analysis of the GPSS results. The GPSS results present the % CPU, including the associated RTOS component, for each processor in the system. Using the % CPU for each processor along with the rate and the processor running time, it is possible to solve directly for RTOS service time.

At this point the question naturally arises "If the % CPU for each processor is given by the GPSS results why not use it directly?" The answer to this question is that if all three quantities are available, the impact of projected improvements to RTOS or changes in rates or running times of processors can be evaluated for their effects on total system loading.

DETAILED RTCC LOADING ESTIMATORS

In this section the RTCC loading data for the various real-time processors of the system is presented in a series of tables. These processors have been grouped into five categories as follows:

1. Telemetry Input Processors
2. Telemetry Display Processors
3. Display Request Processing
4. Trajectory Input Processors
5. Trajectory Display Processors

Figure A.3-1 indicates the general flow of data between these five groups of processors. These groupings have been selected to permit estimation of loading for the various RTCC system organizations under consideration in the Augmentation II study effort.

The use of this data in estimating RTCC loading is described in the paragraphs below.

Telemetry Inputs

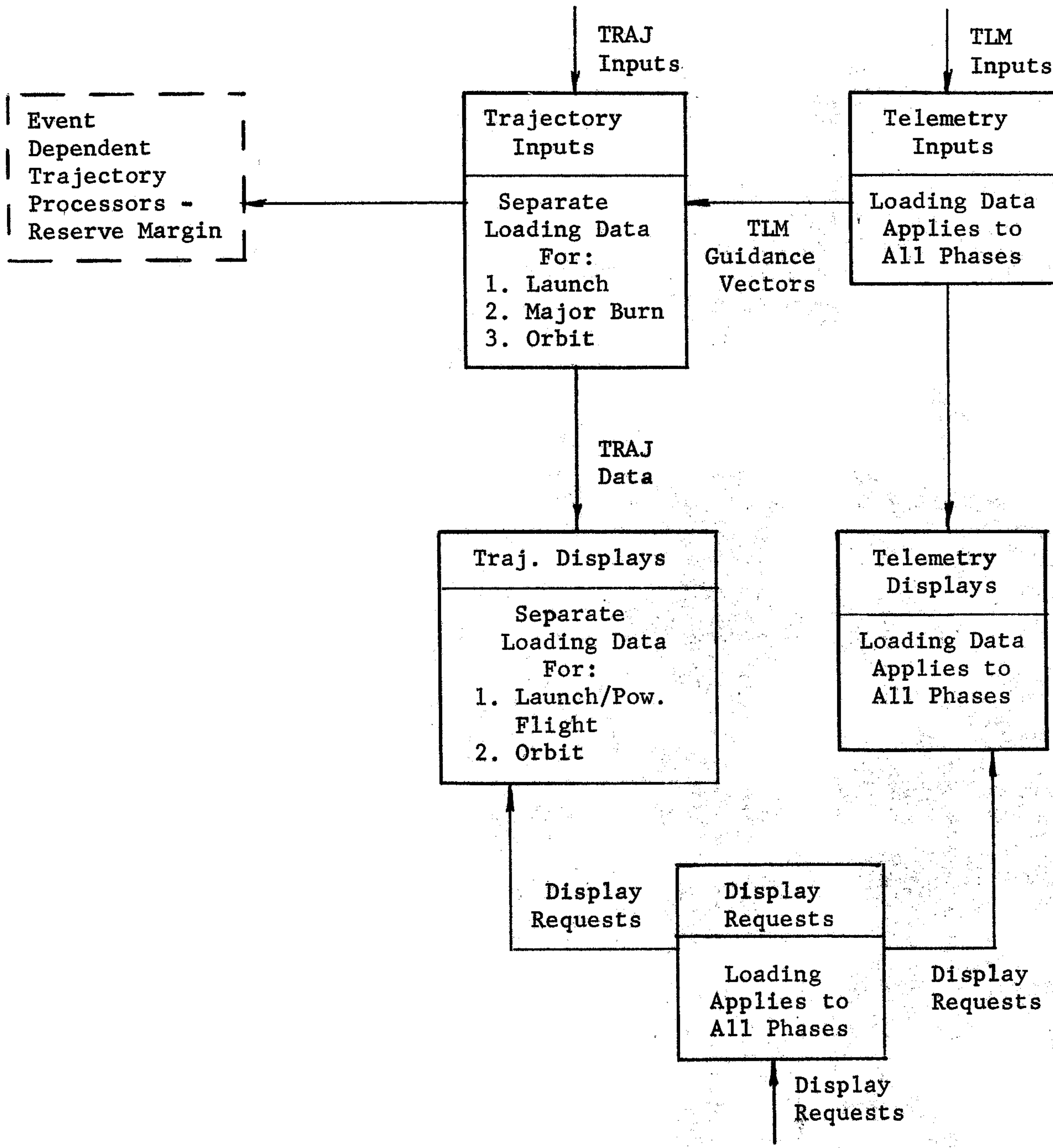
To determine the load imposed by the processing of telemetry inputs, it is necessary to describe the vehicle telemetry sources which are actively sending data to the Mission Control Center. Table A.3-I lists for each telemetry source the associated % CPU load. This data is applicable to all mission phases in which the telemetry sources are active. The % CPU shown in the table is based on a rate of one telemetry frame per second per vehicle. Changes in the rate can be reflected by appropriate scaling of the % CPU load as follows: double the rate, double the load ...,half the rate; half the load ..., etc.

Telemetry Display Loading

Table A.3-II indicates the three components of the telemetry display load; these are the TV display load, the events and alarms load and a load imposed by the program which supervises the generation of guidance computer TV displays. The % CPU for each of these components is parameterized by one of the following three items: the number of telemetry sources (j), the number of guidance computer sources (k), and the number of TV displays being updated (n).

Figure A.3-1

RTCC DATA PROCESSING FUNCTIONS



The number of telemetry sources j is a direct carryover from the number of sources identified for telemetry input processing. The number of guidance computer sources is a count of all AGC, LGC or S-IVB/IU sources which are active. The number of TV displays can be supplied in any of several ways. IBM currently models the number of telemetry displays by assuming five per CSM, two for every other telemetry source, plus one for each guidance computer. This assumption will be applied in our evaluation of loading. It should be noted that telemetry displays are tied to the one frame per second telemetry input rate; changes in the rate will result in a need to appropriately scale the % CPU indicated in the table.

Display Request Processing

Display request processing covers the initial handling of requests for displays, the allocation of TV channels and the maintenance of the TV guide table. Table A.3-III indicates the loading to be included for this function. This load should be considered for any computer which has direct interface with the TV system.

Trajectory Input Processors

The loads imposed by trajectory input processors vary with mission phase. Tables A.3-IV, V and VI give the loading imposed by inputs for one tracked vehicle for launch, major burn, and orbit phase respectively. It should be noted that the determining factor for trajectory input loading is the number of high speed or low speed tracking sources feeding data to the RTCC and that the data for the major burn was approximated by considering the major burn to be a case similar to launch with fewer input sources and no requirement for the last three processors in Table A.3-IV which provide computations peculiar to launch. It should be also noted that the orbit phase trajectory input processing, Table A.3-VI, includes some display processing.

Trajectory Display Processing

Trajectory display processing loads for both launch and major burn flight phases were taken from the GPSS Launch/Hold simulation. Table A.3-VII presents the data for these processors. As in the case of trajectory input processing the assumption is made that the display load during major burns will be similar (in this case identical) to the display load for launch.

Trajectory display loads for the orbit phase data collection period were partially covered under trajectory inputs. The remaining trajectory displays are covered by the .23% indicated in Table A.3-VIII. This load is low due to the low update rate of these displays, once every 12 seconds.

SUMMARY OF LOADING ESTIMATORS

This section presents a condensed version of the data presented in the previous section. A summarized % CPU load for each telemetry source and tracked vehicle is presented in Table A.3-IX. These summary loads are immediately useable if one assumes the current data rates, processor running times, numbers of TV displays per telemetry source and the like. If it is desirable to change any of these parameters, a more detailed consideration of the data presented in the previous section is required.

The telemetry loading data presented at the top of the table gives three % CPU loads for each vehicle: the input processing, the display and the total telemetry loads. Associated with each vehicle are the three parameters j, k, and n which indicate the number of telemetry sources, guidance computers, and TV displays associated with each vehicle. These three parameters were used in conjunction with the data in Table A.3-II in establishing the total display load in the summary table.

The trajectory and the display request loading data are simply a retabulation of the totals which were presented with each of the detailed tables in the previous section.

It should be noted that the loading estimators presented in the table only cover the real-time loads borne by the system. The load imposed by the event-dependent trajectory processing must be handled by reserving an appropriate margin of capacity, as discussed earlier. Margin requirements vary with the number of vehicles for which trajectory computations must be performed and can be best examined on a case by case basis.

Table A.3-I

TELEMETRY INPUT PROCESSING-ALL PHASES

Telemetry Source	Processor Name	Rate (uses/sec)	Processor Running Time (sec)	RTOS Running Time (sec)	% CPU
SI	AQXIB	1.0	.004930	.013270	1.82
S-IVB/IU Launch	LSB4I		.009500	.018200	2.77
S-IVB/IU Orbit	AQIUI		.009500	.018200	2.77
CSM Non-AGC	AQCSM		.006290	.015510	2.18
CSM AGC Portion	AQAGC		.005790	.014210	2.00
LEM Non-LGC	AQLEM		.005540	.015360	1.91
LEM LGC Portion	AQLGC		.005790	.014210	2.00
LEM Abort Computer (LAC)	AQYIV		.005790	.014210	2.00
S-II* (like an SI)			.004930	.013270	1.82
S-IC* (like an SI)			.004930	.013270	1.82
EM* (like non-LGC LEM)			.005540	.015360	1.91

* These three telemetry sources were not modeled by IBM in the 278 Simulation; the values for rates, running times and % CPU are assumed to be the same as those of the telemetry sources named in each case.

Table A.3-II

TELEMETRY DISPLAYS-ALL PHASES

Display Type	Processor Name	Rate Users/Sec	Processor Running Time (Sec)	RTOS Running Time (sec)	% CPU
TLM TV Displays for n displays	AOUTP	1n*	.003000	.004330	.733n
TLM Events & Alarms for j sources	AEVAL	1j	.002445	.008155	1.06j
TLM Guidance Digitals for k Guidance Sources	AXGDN	1	.002480	.013825 + k X .002765	1.62 + k X .28

* Note IBM modeled TV displays as follows for 207/208:
n = 5 per CSM + 2 per other TLM source + 1 per Guidance Computer

Table A.3-III

DISPLAY REQUEST + TV CONTROL-ALL PHASES

	Processor Name	Rate Uses/Sec	Processor Running Time (sec)	RTOS Running Time (sec)	% CPU
Display Request Interpreter	RFFDP	r*	None, all RTOS	.012900	1.29r

* r is number of requests per second currently modeled at .75/sec.

Table A.3-IV

TRAJECTORY INPUT PROCESSING
LAUNCH PHASE

Trajectory Process	Processor Name	Rate Uses/Sec	Processor Running Time (sec)	RTOS Running Time (sec)	% CPU
S-IVB Vector Input	AQTLM	2	.000570	.002550	.624
LGC or Vector Input AGC	AQCST	2	.000570	.002550	.624
S Band Input	AQSBD	2	.000610	.002270	.576
IP Raw Input	AQIPR	2	.000610	.002270	.576
Ship C Band Input	AQSHP	2	.000550	.001070	.324
IP Smooth Input	AQIPS	2	.000550	.001070	.324
Data Quality	AMDQL	10	.000610	.001214	1.824
Raw Radar Edit	AMRED	4	.002240	.000790	1.212
Raw Radar Smooth	AMRSM	4	.001750	.000680	.972
Selected Source	AMSDP	2	.002420	.000760	.636
Entry Interface	AVGEI	2	.001360	.000560	.384
Mode II Impact	AMIIP	2	.001980	.000660	.528
Hold Phase Check	ASLNM	2	.000170	.000790	.228
				TOTAL	8.832

Table A.3-V

TRAJECTORY INPUT PROCESSING
MAJOR BURN

Trajectory Process	Processor Name	Rate Uses/Sec	Processor Running Time (sec)	RTOS Running Time (sec)	% CPU
S Band Input	AQSBD	2	.000610	.002270	.576
Guidance Input	AQCST	2	.000570	.002550	.624
S-IVB Input	AQTLM	2	.000570	.002550	.624
C Band Input	AQSHP	2	.000550	.001070	.324
Data Quality	AMDQL	6	.000610	.001214	1.094
Selected Source	AMSDP	2	.002420	.000760	.636
Raw Radar Edit	AMRED	2	.002240	.000790	.606
Raw Radar Smooth	AMRSM	2	.001750	.000680	.486
				TOTAL	4.970

Table A.3-VI

TRAJECTORY INPUT PROCESSING (includes some displays)
ORBIT PHASE - DATA COLLECTION PERIOD

Trajectory Process	Task Name	Rate Uses/Sec	Processor Running Time (sec)	RTOS Running Time (sec)	% CPU
Low Speed Input	BTLSDC	.66*	.003080	.024650	1.83

* This represents a worst case of four stations, each sending a 1 return per 6 sec.

Table A.3-VII

TRAJECTORY DISPLAY PROCESSING
LAUNCH OR MAJOR BURN PHASES

Trajectory	Processor Name	Rate Uses/Sec	Processor Running Time (Sec)	RTOS Running Time (Sec)	% CPU
Traj DDDs	AXLDD	2	.001070	.010430	2.30
Traj TV & XY Plots	AXLDF	2	.001940	.014860	3.36
				TOTAL	5.66

Table A.3-VIII

OTHER TRAJECTORY DISPLAYS
ORBIT PHASE - DATA COLLECTION PERIOD

CPU = 0.23%, Load is light due to low update rate of 1 per 12 sec

Table A.3-IX

SUMMARY OF RTCC LOADING ESTIMATORS
EXPRESSED IN %CPU OF A 360/75 SYSTEM

TELEMETRY LOADING DATA:
For all Mission Phases by Vehicle Type

Vehicle	Input Processing	Display Parameters j	k	n	Total Display Load	Total TLM Load
S-I, S-IC or S-II	1.82 %	1		2	2.53%	4.35%
S-IVB/IU Launch	2.77	1	1	3	3.54	6.31
S-IVB/IU Orbit	2.77	1		2	2.53	5.30
CSM	4.18	2	1	8	8.26	12.44
LM without LAC	3.91	2	1	5	6.06	9.97
LM with LAC	5.91	3	2	8	9.60	15.51
EM	1.91	1		2	2.53	4.44

For all cases involving at least one Guidance Computer, add 1.62% to display processing load and include in total load.

TRAJECTORY LOADING DATA:
Per Tracked Vehicle

Vehicle Phase	Trajectory Inputs	Trajectory Displays	Trajectory Total Load
Launch	8.83%	5.66%	14.49%
Major Burn	4.97	5.66	10.63
Orbit	1.83	.23	2.06

DISPLAY REQUEST LOADING:

Per computer which processes requests .97%

APPENDIX A.4

AUGMENTATION II RTCC COMPUTER HOUR ESTIMATION

INTRODUCTION

This paper presents a model for estimating the number of computer hours which will be required to support post-Apollo missions. The data presented in this report has been extracted from the monthly utilization statistics prepared by IBM covering the period from January 1963 through November 1966 with particular emphasis being placed on the most recent fifteen months.

The report is divided into two sections. The first describes each of the current activities for which the RTCC computers provide support, presents data in graphic form on the current level of activity and attempts to estimate a computer hour requirement for the post-Apollo era. The data is developed in terms of hours per month required on a 360/75 system to provide a common basis for extrapolating current level activities into post-Apollo era. (Multiplying factors are provided to permit the consideration of other machines in the 360 series.) The second section summarizes the data from the first and gives an example of how the data may be used to estimate computer hours for a representative operational configuration.

COMPUTER HOURS ESTIMATORS

The current activity of the RTCC has been broken down into the following categories of productive time:

(a) Mission Program Development

(b) GSSC Program Development and Operational Support

(c) Dynamic/Script Development

(d) ORACT Development and Operational Support

(e) Systems Analysis

(f) 7094 EXECUTIVE Development

(g) RTOS Development

(h) Engineering and M & O Support

(i) Project Management and Administration

(j) Operational Support

(k) NASA Computer Center Branch

(l) NASA Computation and Analysis Division Support

Each of these activities is discussed in a subsequent paragraph. In each case the current load, and factors which can be expected to influence the load in the future, are discussed. Non-productive time required for maintenance, set-up, equipment modifications or idle is provided by assuming the current experience of 195 hours per month per computer.

Mission Program Development

Mission Program Development support consists of the following: program unit testing, program subsystem testing, program system testing, compilation and linkage editing support, and the miscellaneous job shop support which is required in preparing the mission programs. In short, mission program development covers all support required in preparing and maintaining the mission programs; it does not include the use of these programs during simulated or live missions. Figure A.4-1 indicates the history of mission development support over the fifteen month time period. As indicated in the figure the support was provided on three different classes of machines.

The support was provided in two different modes of operation on the 7094 and 360/75 systems; these modes are distinguished as block time runs and job shop runs. In a block time run the user schedules a block of time and uses the time allotted. When used in this fashion differences in the speed or power of the machine do not make a difference in the amount of hours required for program testing since the user has a fixed number of minutes available. In the job shop run the user submits a job for processing and the machine will process the job to completion in a time which is a function of the speed or power of the machine.

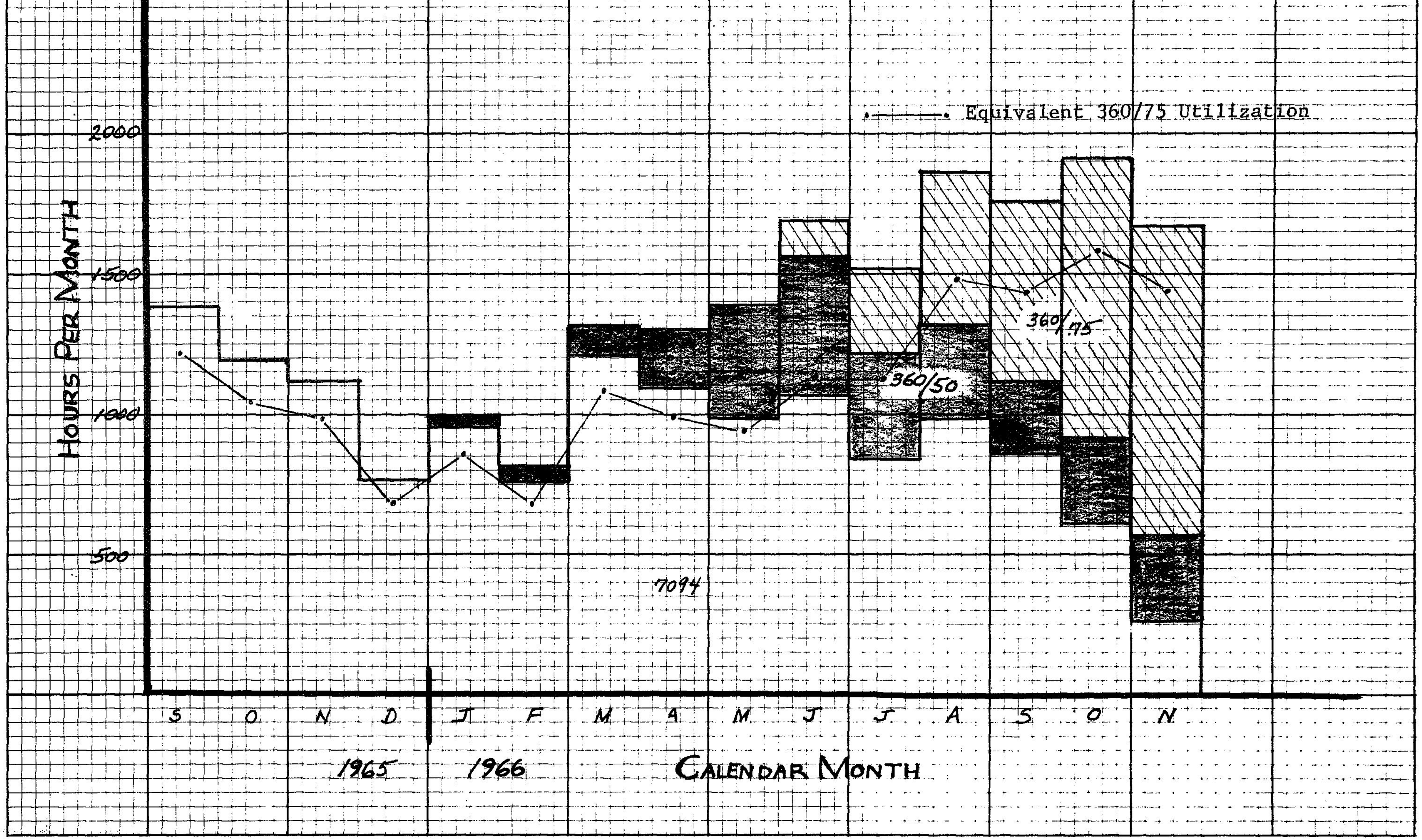
In order to convert the utilization figures to their 360/75 equivalents the following assumptions will be made about the mix of block time and job shop jobs on the 7094s and 360/50s, and the speed of 360/50 and 7094 systems relative to the 360/75.

System	% Time in Job Shop Mode	Relative Speed
7094	20	.4
360/50	100	.2

Since a detailed breakdown of the modes in which individual jobs were run has not been made, these assumptions are based on the following information. It is the author's understanding that the 360/50s, were configured for and used in a job shop mode at all times. During the month of November the 7094s were used in a job shop mode for approximately 20% of the production time associated with the development of Mission, GSSC, ORACT, Dynamic Script and EXECUTIVE programs. It is assumed that this 20% applies equally to all of these users. The speed of the 7094 relative to the 360/75 has been taken from the "Definition of APOLLO Launch/Hold Model 207LH-1," 6 September 1966, IBM.

FIGURE A.4-1

COMPUTER UTILIZATION FOR
MISSION PROGRAM DEVELOPMENT



The speed of the 360/50s relative to the 360/75 were taken from a memo by Wayne Stanley, 15 June 1966, entitled "RTOS Performance for Mod 75 Utilizing GMT Clock." In the study the running times of RTOS routines resident in main core were compared thus providing a comparison of central processing unit speeds. In a later report System/360 Utilization reports were analyzed to obtain a time per job shop run for Model 75 and Model 50 computers. (See IBM Technical Report by C. L. Smith, "A Review of RTCC Computer Utilization Predictions for System 360 Equipment.") This latter report concludes that a Model 50's hour is equal to half of a Model 75's hour. This report does not take into account any differences between the kinds of jobs run which naturally raises questions about the validity of the result. Furthermore, the sample was based on the current limitation of RTOS which only permits a single job to be active at one time. This limits the system's effective speed by not permitting multiprogramming among jobs. It is expected that the implementation of a multijob capability around mid-1967 will improve the effective speed of the 360/75 and provide the speed advantage implied by the relative speeds of the central processors.

Figure A.4-1 also includes the adjusted total utilization derived by applying the assumptions concerning block time/job shop mix and the relative speeds of the 7094 and 360/50 systems. The relative speed advantage is applied against the job shop load only. The equivalent utilization is expressed in the following relationship:

$$U_{75} = U_n \ (F_B + F_J \ S_n)$$

U_{75} = The equivalent utilization on a 360/75

U_n = The utilization on a computer model n, where n = 7094 or 360/50

F_B = Fraction of time spent in block time mode

F_J = Fraction of time spent in job shop mode

S_n = Speed of the model n computer relative to 360/75

Applying this relationship for the 7094 and 360/50 computers yield:

$$U_{75} = U_{7094} \ (.80 + .20 \times .40) = .88 \ U_{7094}$$

$$U_{75} = U_{360/50} \ (0 + 100 \times .20) = .20 \ U_{360/50}$$

The development time indicated in Figure A.4-1 was expended in preparation for mission listed in Table A.4-I. The normal development cycle of a mission package extends over a period of six months. Some time had been expended on missions prior to the sample interval and some mission packages had not been completely developed by the end of the sample interval. The column on the right indicates the number of months that the mission programs were under development in the sample interval.

TABLE A.4-I

SCHEDULED DEVELOPMENT TIME WITHIN SAMPLE

Mission Interval	Development Time
GT-7/6	3 months
GT-8	5
GT-9	6
GT-10	6
GT-11	4
GT-12	6
AS-201	3
AS-202	8
AS-203	7
AS-204	7
AS-205	5
AS-206	4
AS-207/8	1
AS-501	6
AS-502	3
	74 mission months

The expenditure of these 74 mission months of program development time represents the equivalent of a normal six month development cycle for about twelve mission (74/6 $\approx$ 12). This represents a mission density over the fifteen month period of approximately ten missions per year (74/6 x 12/15 = 9.87). The total computer hour expenditure in preparing for missions adjusted to the 360.75 standard was 16,730 hours, or 1,356 hours/mission.

To what extent are these figures applicable to the post-Apollo era? Three principal factors which can contribute to a change in utilization will be discussed; these are: the extent to which new programs must be developed, improvements in the RTOS which will permit more efficient use of the facility, and changes in mission density which affect the rate at which programs must be developed.

First the extent to which new programs will have to be developed will depend on similarity between Apollo and post-Apollo missions. The post-Apollo missions will be flown using the same basic vehicles and systems developed for Apollo. There will, therefore, be a large set of mission programs which are immediately applicable to use in the post-Apollo missions. With the exception of synchronous orbit support programs most of the trajectory related programs will have been tested and put to actual use. These include the launch trajectory, translunar trajectory, lunar ascent, lunar descent, lunar rendezvous and docking, and re-entry programs used in Apollo. In addition most of the telemetry processing associated with boosters and guidance systems will remain constant.

The post-Apollo missions can be expected to differ from the Apollo missions in three ways: more vehicles and systems will have to be simultaneously tracked and monitored, some new instrumentation to support the experiments activities will have to be monitored, and the missions will be of longer duration. Thus the mission program development work will probably take the form of more extensive mission planning programs, the addition of new telemetry programs to monitor the experiments modules and probably some new programs in the area of life systems and electrical power systems required for the longer duration missions.

The net effect of the similarities and dissimilarities between the Apollo and post-Apollo mission can be expected to be a general leveling off or perhaps even a decline in mission program development work for the individual post-Apollo missions. The figure 1,356 hours per mission is an average equivalent 360/75 development time for the missions which were developed over the sample interval. Contained in this average are mission packages which required extensive program development as well as mission packages which were more or less updates of the previous mission package. This average will be applied as the per mission cost of developing post-Apollo mission packages.

The second factor influencing the applicability of the current mission program development load to the post-Apollo era is the increased capability for program development and checkout afforded by the improvements currently envisioned for the 360/75 RTOS. The RTOS as it currently exists will permit multiprogramming within a job but can only run one job at a time. This effectively limits the system to running one unit test, or one subsystem test or one mission package at a time. In most cases of unit and subsystem level tests, sufficient central processor and storage capacity is available to run other tests concurrently but the RTOS does not provide a facility to run more than one job. The implementation of a multi-job capability for the job shop environment mentioned above will probably be extended to the block time environment and permit multiple users to develop and checkout programs in real-time.

The increase in performance afforded by adding the multi-job capability is different for the job shop and block time mode applications. In the job shop case the addition of the multi-job capability permits the machine to be run at or near its full capacity. In the case of the block time operation the multi-job capability allows several programmers to use the machine during the same block of time but the machine is not necessarily running at or near full capability. In the block time mode the savings are directly a function of how many users can be accommodated at one time. The number of block time users that will actually use the capability will depend on many factors: the size of the jobs, the availability of real-time interfaces and the extent to which they can be shared, the degree of confidence that the programmers and managers have in the system.

Since one can only guess at what the actual usage might be, we will make a guess, label it as a guess and segregate it from the analysis so the reader may substitute his own values if he likes. It is suggested that 60% of the block time utilization for mission program development will continue to be single user applications, that 30% will be shared between two users and that 10% will be shared by three users and that due to practical limitations implied by multiple usage of real-time interfaces no more than three users will be simultaneously accommodated. This distribution yields a utilization factor which can be applied to the number of hours required for block time program development and checkout. The factor is $(.6 \times 1.0) + (.3 \times .5) + (.1 \times .33) = .78$. That is a 22% reduction in utilization would be effected for the above assumptions about shared usage of the machines.

The third factor influencing the applicability of the current mission program development load to the post-Apollo era is the difference in mission density between the sample interval and the post-Apollo schedule. Mission density, measured by the number of missions per year, determines a rate at which mission packages must be prepared. Mission density for the sample interval was indicated above at 9.87 missions per year; analysis of the ML-65-3 and M(P)-2A schedules (Appendix B.2) reveal 11.4 and 8.4 missions per year respectively. The number of computer hours per month will be established by multiplying the number of hours per mission by the number of missions per year and dividing by twelve.

In summary, a per mission cost of program development has been identified (1,356 hours per mission), a possible saving in program development time through multiple jobbing on the 360/75 systems has been estimated at 22%, and the contribution of mission density to the program development and checkout load has been identified. Table A.4-II indicates for a range of mission densities from seven through thirteen the number of computer hours per month required. For each mission density, the number of hours is indicated both with and without the multi-jobbing savings estimated above.

TABLE A.4-II

COMPUTER HOUR REQUIREMENTS FOR MISSION PROGRAM DEVELOPMENT

Density Missions/Year	Hours per Month Required on 360/75 Systems: Without Multi-job Savings	With Multi-job Savings	Comments
7	791	617	
8	904	705	Avg. M(P)-2A schedule (8.4)
9	1017	793	
10	1130	881	Worst Yr M(P)-2A Schedule (10)
11	1243	970	Avg. ML-65-3 schedule (11.4)
12	1356	1057	
13	1469	1146	Worst Yr. ML-65-3 schedule (13)

Referring once again to Figure A.4-1, it can be seen that starting at the first of 1966 there was an increase in the number of computer hours used on mission program development. One might well ask, "Isn't this indicative of future growth, and shouldn't an effort be made to extrapolate this pattern of growth into the AAP era?" This rapid growth is discounted in this report for the following reasons:

(a) The period is characterized by a phaseover from 7094 to 306/75 systems. During this period the number of computer available doubled. It is felt that to a certain extent demand was rising to meet the new supply of computer hours.

(b) Phaseover from one system to the other demands work on all of the programs which are being phased over to add linkage routines compatible with RTOS, and to reassemble and test each program. This is a one time occurrence associated with phaseover.

(c) The learning phase associated with the new systems leads to less efficient use of the computers in the early months of their installation.

(d) The rate of production of new programs was not constant over the year. During the first seven months an average of 4.5 mission programs were under development, during the latter eight months an average of 5.25 mission programs were under development.

Because of the irregularities caused by the phaseover which cannot be accurately determined, it is felt that the extrapolation into the post-Apollo era can best be made by considering the differences in the Apollo and post-Apollo missions (as was done above) and not by an extrapolation of the current rate of increase in mission program development time.

Finally, the prospect of developing the system along functional lines rather than using the current mission package technique is a distinct possibility. This has been proposed in Data Handling Group Meetings for a variety of reasons: to provide smaller and therefore more easily managed programs, to provide easier checkout of programs, to provide more growing room in the computers by loading them less heavily, and to provide a more stable program environment, all of this to result in a higher confidence in the program package. It is not clear to what extent a change to functional organization will effect the number of hours required for developing the programs required to support a given mission. Certainly it will not affect the development of individual program load modules since these are already developed along functional lines (e.g., Telemetry Input, Telemetry Display, Orbit Differential Correction, etc.). The effects will be felt at the system level in two ways: the two (or more) functionally organized systems will have to be tested individually as well as jointly, but they will probably require less extensive individual tesing of the two (or more) functional systems. The net effect could conceivably go either way. Therefore, the option for functional vs. mission organization will not be estimated to materially affect the mission program development time.

The efforts required to provide the initial functional capability are estimated to be small. The individual programs are already designed in functional modules. In order to develop the functional capability the RTOS will have to be modified to provide communication of data and program queues probably via the shared Large Capacity Storage, and a scheme for controlling access to the display devices will have to be implemented.

GSSC Program Development and Operational Support

The Ground Support Simulation Computer, GSSC, provides a capability to simulate network inputs to the Mission Control Center. These inputs are fed via CCATS to an operationally configured RTCC computer, SOC, which is used for flight controller training and operational procedures development. The program development cycle for the GSSC closely parallels the development of the mission programs for a given mission with each mission having a corresponding GSSC program package. Consequently GSSC development and operational support will be viewed as load which varies with mission density.

The history of GSSC Computer Utilization over the fifteen month sample interval is shown in Figure A.4-2. As in the case of mission development, the work was performed on three different classes of machines and in a combination of block time and job shop modes of operation. The conversion of the computer hour utilization to 360/75 equivalents was done in the same manner as indicated above in the preceding section and the resulting equivalent hour expenditures are shown in the figure. The total expenditure over the fifteen month interval was equivalent to 7,720 hours of 360/75 time. Again, using the mission density from Section 2.1, this converts to an expenditure of 626 hours per mission.

In discussing the applicability of this figure to GSSC development in the AAP era only one point will be made. The GSSC program very closely parallels the mission program in that changes from one mission to the next will usually impact both systems in a similar fashion (i.e., if a telemetry parameter is called for by the mission, this requirement will generally impact both the mission programs, which must process and display the new data, and the GSSC programs which are generally modified to provide a capability for simulation of the new telemetry data). Therefore, it is felt that the arguments made previously on the applicability of the mission program experience to the post-Apollo era hold equally well for the GSSC development load.

Table 3 summarizes in similar fashion to Table B.4-II, the monthly expected utilization for GSSC development for a range of mission densities.

FIGURE A.4-2

COMPUTER UTILIZATION FOR
GSSC PROGRAM DEVELOPMENT AND OPERATIONAL SUPPORT

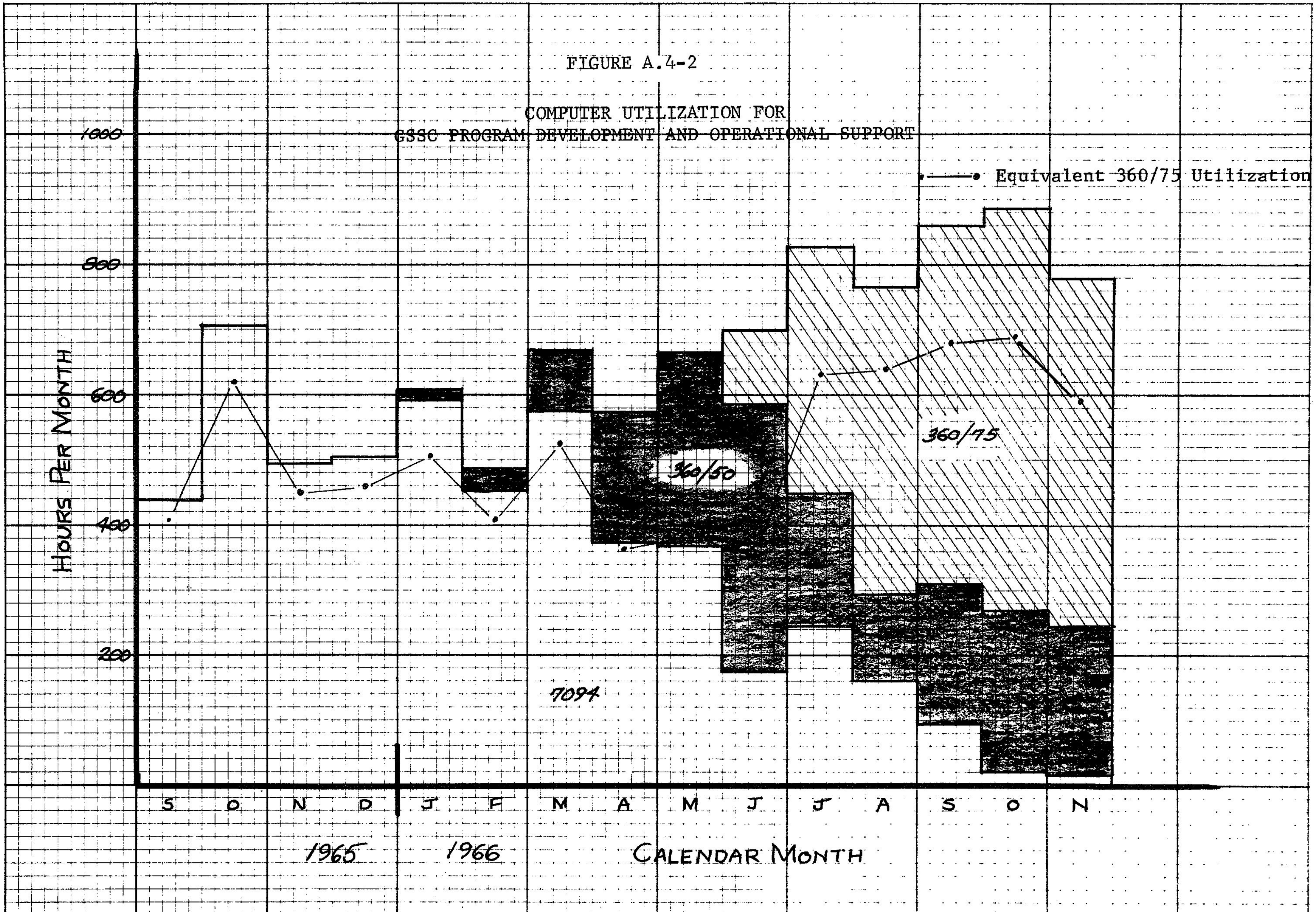


TABLE A.4-III

COMPUTER HOUR REQUIREMENTS FOR GSSC DEVELOPMENT

Density Missions/Year	Hours per Month Required on 360/75 Systems: Without Multi-job Savings	Hours per Month Required on 360/75 Systems: With Multi-job Savings	Comments
7	365	284	
8	417	325	Avg. M(P)-2A yr. (8.4)
9	469	366	
10	521	406	Worst M(P)-2A Yr. (10)
11	573	447	Avg. ML-65-3 Yr. (11.4)
12	625	488	
13	678	528	Worst Case ML-65-3 Yr. (13)

Two observations should be made concerning the GSSC. First, the phaseover to 360/75 and the increased mission density affected the GSSC development load in a fashion similar to its affects on the mission program development load; consequently the increase in activity in the latter half of the sample interval is not viewed with alarm. Second, the movement of the GSSC to Building 422 practically limits its development work load to 525 hours a month (one machine's worth of useful time). This corresponds to a mission density of ten missions per year without multi-job savings. The preparations for Apollo missions will probably require an increase in GSSC development on a per mission basis; however, the schedule for the coming year indicates only six or seven missions. The isolation of the GSSC in building 422 can be looked upon as providing some 30 to 40% potential extra capacity to get ready for Apollo and sufficient capacity to handle a post-Apollo and sufficient capacity to handle a post-Apollo schedule of up to ten missions per year.

Dynamic/Script Program Development and Support

Dynamic Script are two tools used by mission programmers to generate simulated real time inputs for the checkout of mission programs. Because their development and usage closely parallels the development work on mission programs, the hours required for Dynamic/Script will be assumed to exhibit similar sensitivity to mission complexity and mission density as do the mission programs.

The utilization of computer hours for Dynamic/Script is shown in Figure A.4-3. Without belaboring the question of similarity any further, the number of computer hours to support Dynamic/Script in the post-Apollo era shown in Table A.4-IV was calculated in the same manner as the data in Table A.4-II.

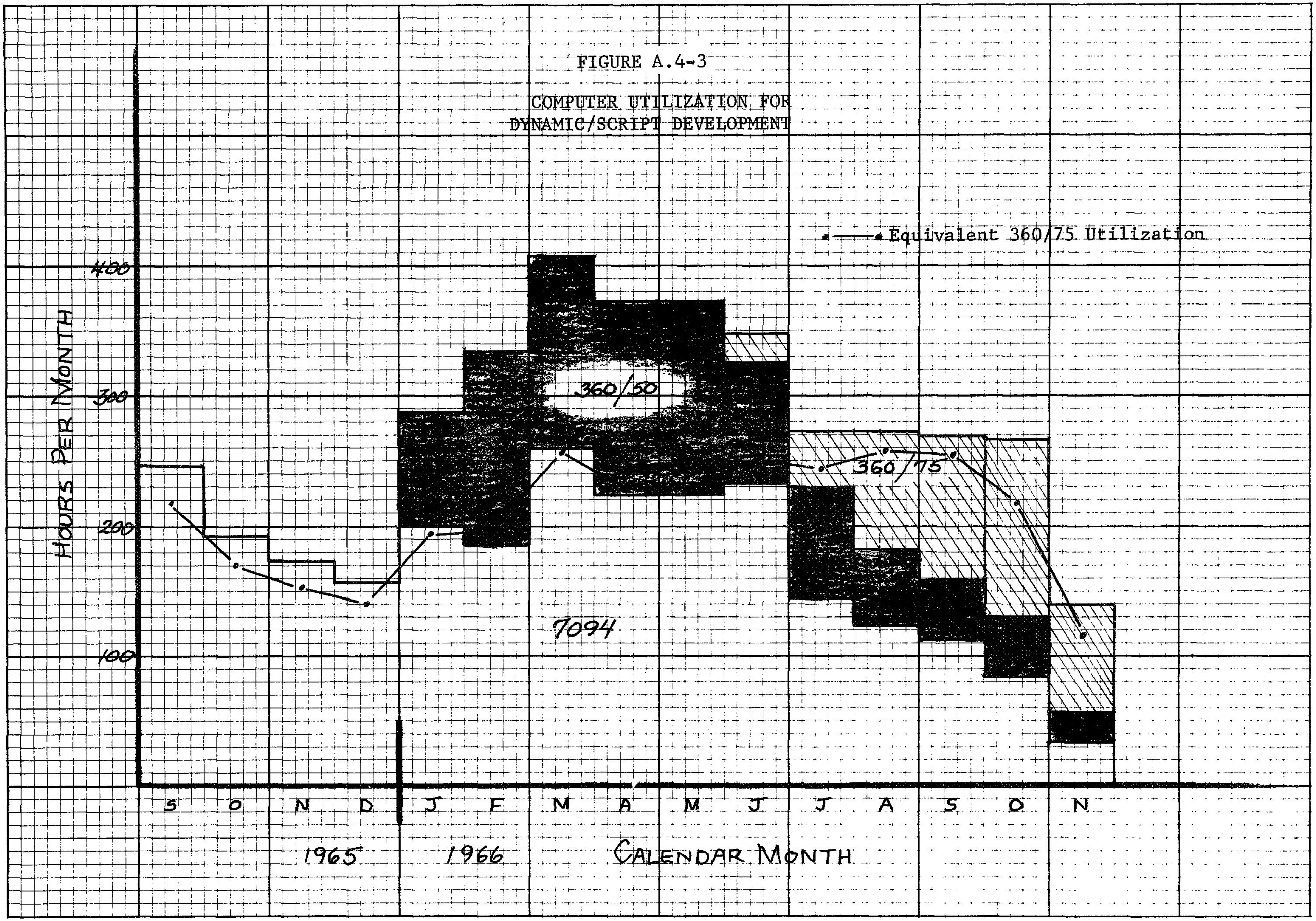


FIGURE A.4-3
COMPUTER UTILIZATION FOR
DYNAMIC/SCRIPT DEVELOPMENT
Equivalent 360/75 Utilization
HOURS PER MONTH
400
300
200
100
360/50
360/75
7094
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
1965
1966
CALENDAR MONTH

TABLE A.4-IV

COMPUTER HOUR REQUIREMENTS FOR
DYNAMIC/SCRIPT DEVELOPMENT & SUPPORT

Density Missions/Year	Hours per month required on 360/75 Systems Without multi-job Savings	With multi-job Savings	Comments
7	147	114	
8	168	131	Avg. M(P)-2A Yr. (8.4)
9	189	147	
10	210	164	Worst M(P)-2A Yr. (10)
11	231	180	Avg. ML-65-3 Yr. (11.4)
12	252	196	
13	273	213	Worst Case ML-65-3 Yr. (13)

One interesting side point is the fact that Dynamic/Script reached its peak in utilization in the months of March through May, whereas the peak for Mission Program development occurred in August through October. Perhaps this is only a reflection of the fact that the development of the tools to do a job preceeds actually doing the job.

ORACT Development and Support

ORACT Programs are used primarily to checkout the interfaces and data flow between the RTCC and the CCATS processors. During the sample interval the utilization of computer hours, see Figure A.4-4, shows two distinct peaks. One peak was associated with the preparation period for Gemini 7/6 and the second peak was associated with the integration of the CCATS system. Both of these peaks are one time occurrences, and the number of hours per month can be expected to subside to a lower level when the CCATS integration is completed.

The total equivalent 360/75 utilization over the sample interval was 3,003 hours. This represents an average utilization of 200 hours per month over the fifteen month interval. Approximately 85% of the hours were expended in direct operational support associated with the nine missions which were conducted in the sample interval. The reamining 15% was devoted to development of the ORACT Programs.

Figured on the basis of nine missions the ORACT requirements average 333 hours per mission. Table A.4-V indicates for various mission densities the number of hours per month required for ORACT development and operational support. It should be noted that a column indicating multi-job savings is not included. A very large part of the work is operational support (85%) and it is doubtful that these system checkout runs would be multi-jobbed with other users. Applying the usual 22% savings to the remaining 15% program development work would yield only a 3% savings.

FIGURE A.4-4

COMPUTER UTILIZATION FOR
ORACT DEVELOPMENT AND OPERATIONAL SUPPORT

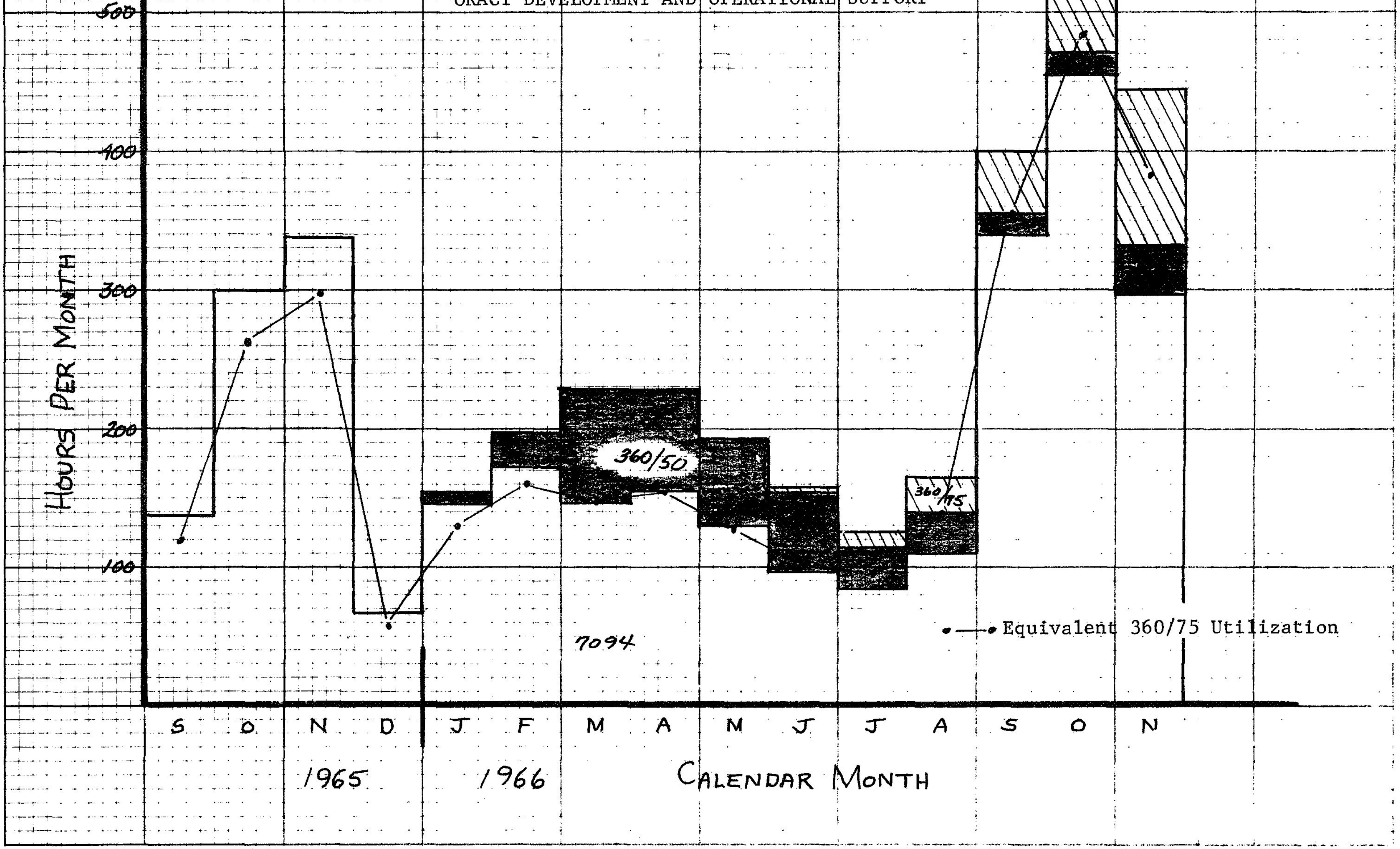


TABLE A.4-V

COMPUTER HOUR REQUIREMENTS FOR ORACT DEVELOPMENT AND SUPPORT

Density Missions/Year	Hours per month required on 360/75 Systems	Comments
7	194	
8	222	Avg. M(P)-2A Yr. (8.4)
9	250	
10	277	Worst M(P)-2A Yr. (10)
11	305	Avg. ML-65-3 Yr. (11.4)
12	333	
13	360	Worst Case ML-65-3 Yr. (13)

Systems Analysis

The systems analysis activity at IBM is primarily concerned with developing the design of the system hardware and software. The principal tool used in systems analysis is a model of the system which permits the analyst to examine the loading and time delays in the RTCC computers. Through the use of these tools it is possible to predict for a given application the percentage of available central processor time used, the usage rates of I/O devices and the amount of time required to complete given processing loads. The system models are also valuable for experimenting with proposed operating system design improvements and in determining the capacities and speeds of storage and I/O devices which best suit the program application. The development and production runs for the systems models are run in the job shop environment and constitute the greater portion of this category's use of computer hours.

The second category of system analysis work encompasses the development and use of the Statistics Gathering System (SGS). This latter tool is run in block time as an adjunct to the RTOS (or EXECUTIVE in the case of 7094 systems). The SGS is used to measure quantities similar to those measured by the systems models and provides a means for calibrating the systems models. This work load constitutes the smaller portion of the system analysis activity. During the sample interval the SGS runs were made only on the 7094 computers and are estimated to have comprised no more than 20% of the total number of computer hours on that system.

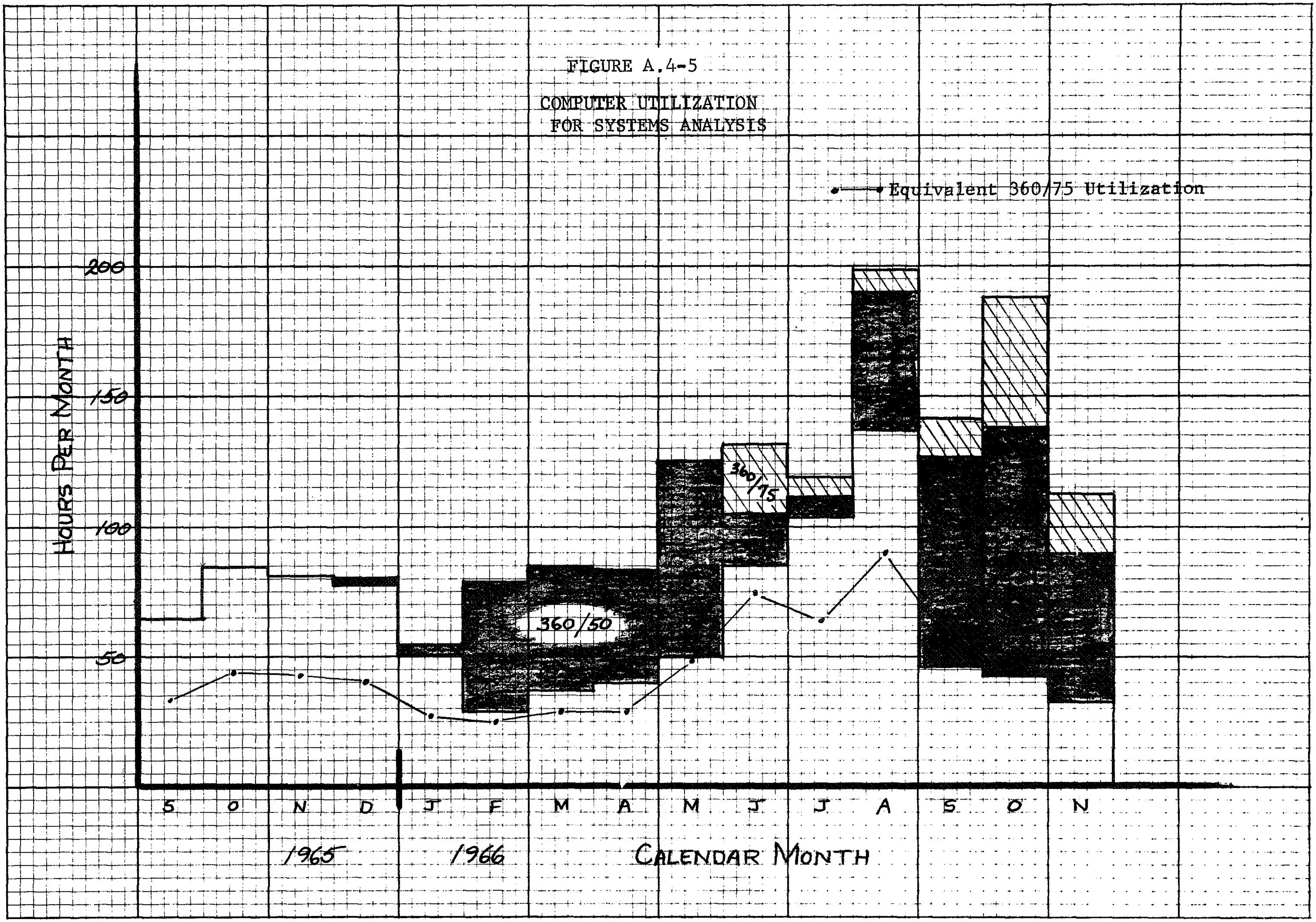
The conversion of system analysis computer hours to 360/75 equivalent will therefore use the following factors:

For 7094 $\quad U_{75} = U_{7094}\ (.20 + .80 \times .40) = .52\ U_{7094}$

For 360/50 $\quad U_{75} = U_{50}\ (0 + 1.00 \times .20) = .2\ U_{50}$

FIGURE A.4-5

COMPUTER UTILIZATION
FOR SYSTEMS ANALYSIS



The resulting adjusted 360/75 utilization and the actual number of hours used on the three different types of systems are shown in Figure A.4-5. The total adjusted hours over the sample interval was 747 hours or an average utilization of 49.8 hours per month.

The current level of activity in systems analysis clearly exceeds the fifty hours per month average and this extensive modeling and development work can be expected to continue through 1967 at the current plateau of about 75 hours per month on a 360/75. The modeling activity generally preceeds the system being modeled by a year or sometimes two years so modeling activity in the post-Apollo era will be looking at what lies beyond post-Apollo. It is perhaps safe to assume that this load will carry over into the post-Apollo era at the 75 hour per month level.

7094 EXECUTIVE and RTOS Development

The computer hour requirements for 7094 EXECUTIVE and RTOS Development are considered together in this section because they are similar programs and phaseover to 360 systems ends the EXECUTIVE development cycle and replaces it with the RTOS development cycle.

Figure A.4-6 and A.4-7 indicate the utilization of computer hours in the development of the two systems. During the period from September 1965 through April 1966, the 7094 EXECUTIVE was in a period of continuing system improvement which required about 100 hours a month. From May 1966 to the end of the sample interval the system improvement work declined to the routine maintenance level as the 7904's were being phased out. During the same fifteen month period, the RTOS was being developed by making modifications to Operating System/360. The initial system development spans most of the interval and RTOS has achieved an initial level of operational capability.

During the year of 1967, several major RTOS system improvements can be expected; these include spooling in February and the implementation of a multi-job capability probably around the middle of 1967. Other improvements which can be expected are the integration of the 2911 switching system, shared LCS and the intercomputer communication, and the development of software for sharing the display and control interfaces.

In order to establish some sort of bounds on the problem of predicting the RTOS development load in the post-Apollo era, two facts about past history of 7094 EXECUTIVE and RTOS development are used to establish limits on the expected utilization:

(a) During the 7094 EXECUTIVE development cycle about 100 hours per month were used for system improvements. At least this much should be predicted for RTOS since it is a larger and more complex system.

(b) The development of RTOS has subsided to a level of about 400 hours a month without an adjustment for differences between 360/50 and 360/75 systems. This would seem to establish an upper bound for that mix of machines.

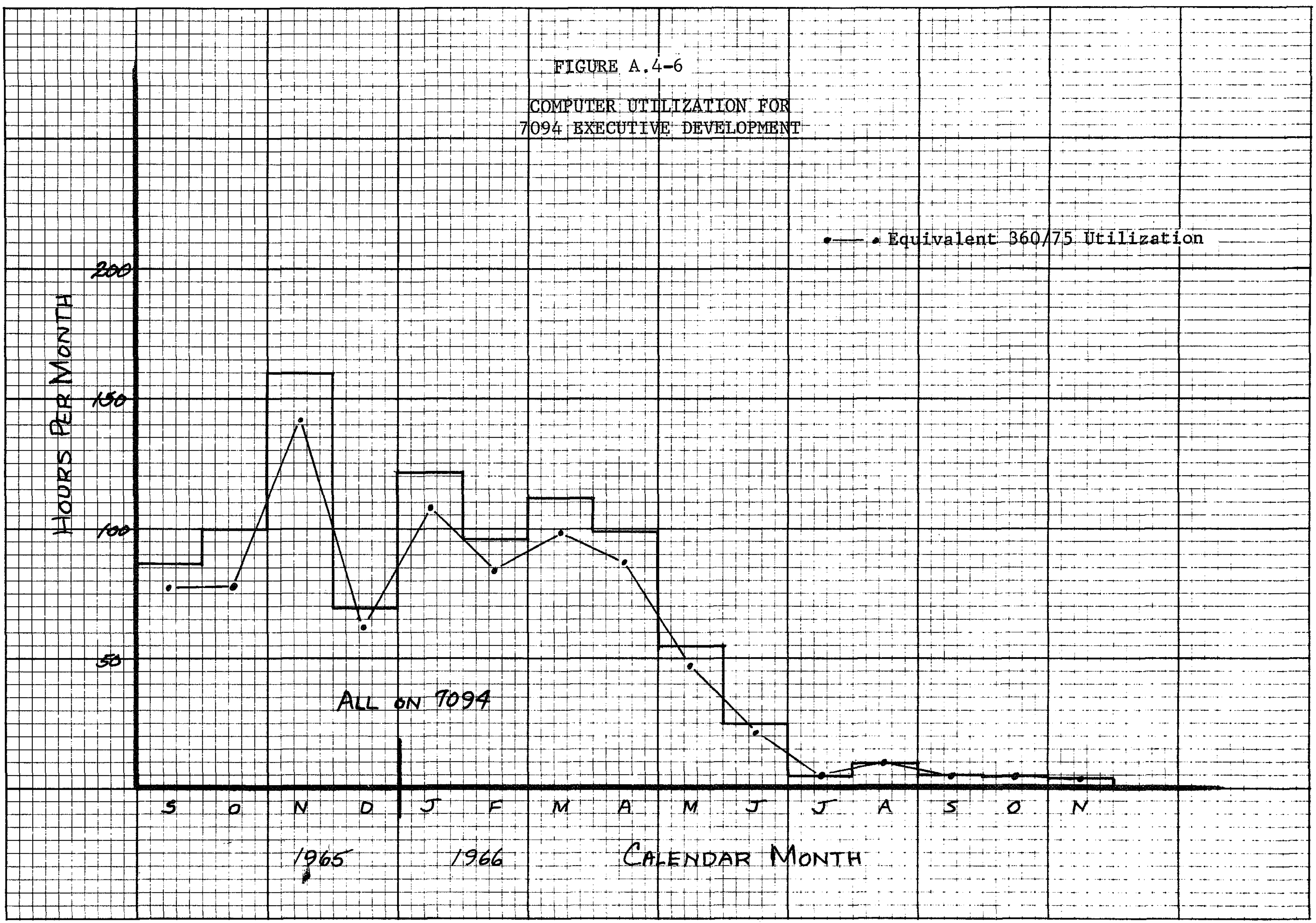
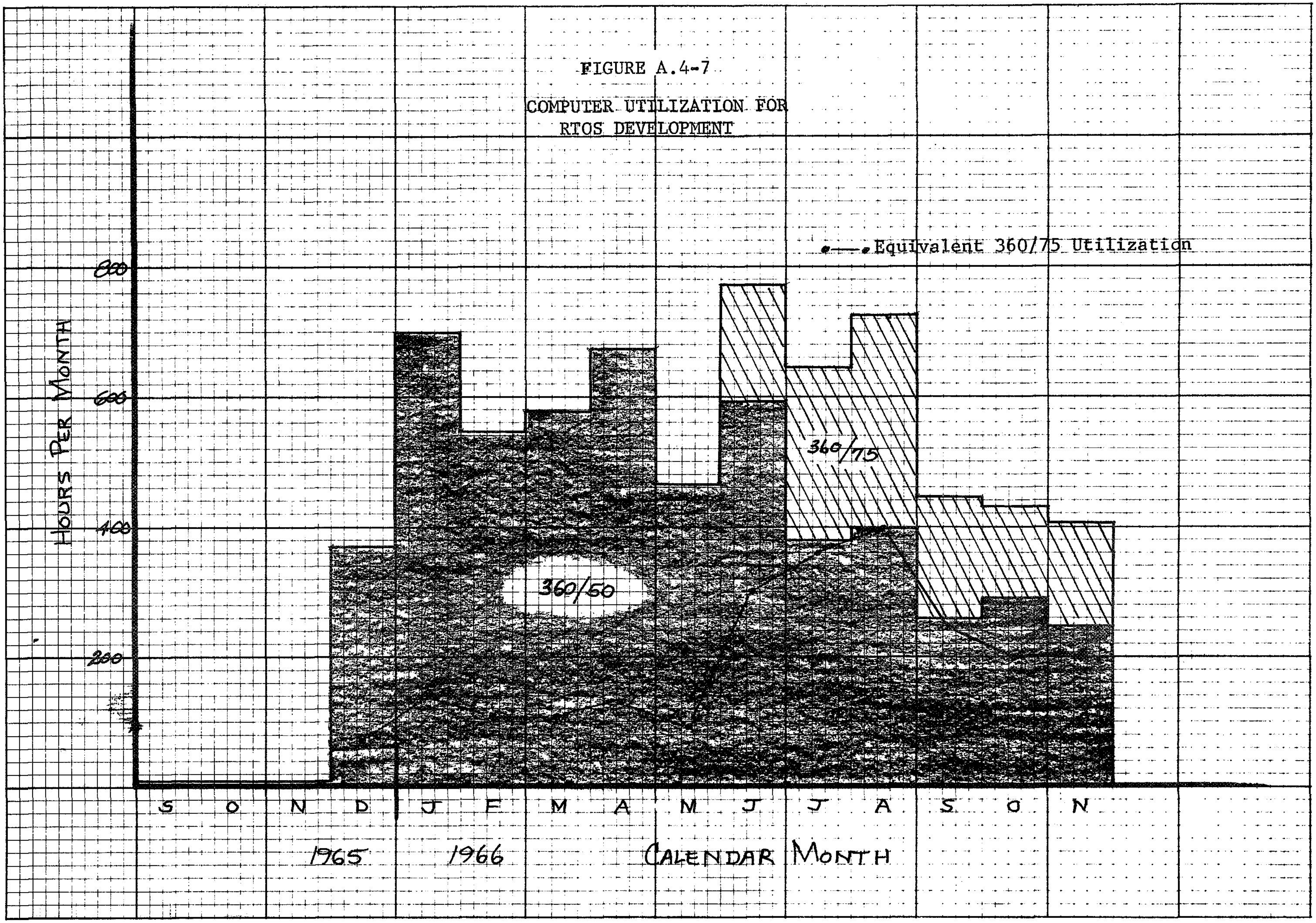


FIGURE A.4-6

COMPUTER UTILIZATION FOR
7094 EXECUTIVE DEVELOPMENT

FIGURE A.4-7

COMPUTER UTILIZATION FOR
RTOS DEVELOPMENT



The equivalent 360/75 utilization indicated in Figure 7 was calculated using a Model 50 hour as equivalent to .2 of a Model 75 hour. It is doubtful that if 360/75 systems were available in the months from December 1965 to May 1966 that the utilization would have been as low as indicated in Figure A.4-7, since the development work on RTOS is not a conventional job shop production application. A considerable amount of the operation consisted of running through short routines, and taking core dumps to determine if indicators and tables were being properly set. This would tend to negate a large part of the speed advantages of the 360/75 were it used in this fashion, since the bulk of the time in the operation is not spent in computing, in which the 360/75 has a speed advantage, but in outputing the data, in which case the speed is determined by the speed of the peripheral device. Toward the latter months of the sample period (September - November) a greater portion of the time on 360/50 systems was used in a more conventional job shop application. In this latter period the conversion of Model 50 hours to their Model 75 equivalents by using the .2 ratio is perhaps more accurate.

The monthly utilization rate has subsided to a level of about 200 hours per month (360/75 equivalents). This figure will be used as the per month cost for system improvements and maintenance of RTOS for the post-Apollo era. Multi-job savings are not indicated because it is doubtful that other programs could be usefully run during testing of RTOS.

Miscellaneous Users

In this section the computer utilization for several miscellaneous users have been brought together because their utilization is not clearly related to the mission density. These users will be briefly discussed and a single estimate will be associated with each.

Computer utilization for Engineering and M & O Job Shop is shown in Figure A.4-8. The time associated with these two tasks require that the computers be up and operating, that is the M & O Job Shop does not include down time for either scheduled or unscheduled maintenance. M & O Job Shop, which accounts for over 80% of the hours in this category, is used for such programs as Utilization Reports, Audits and Spare Parts Accounting. Engineering requires fewer hours and is concerned primarily with the installation and initial checkout of new equipment. For this set of users 200 hours per month in 360/75 equivalent hours will be allocated.

Computer Utilization for Project Management and Administration shown in Figure A.4-9 experienced a growth to around 100 hours per month and has subsided to about thirty hours per month. It is assumed that this peak was associated with either the development of some new programs in this area, or the phaseover and checkout of these programs for the 360 system computers. For this user 25 hours per month in 360/75 equivalent hours will be allocated.

Computer Utilization by Computer Center Branch for RTOS evaluation shown in Figure A.4-10 averages about 17 hours a month 360/75 equivalent hours over the last seven months of the interval. While this activity

FIGURE A.4-8

COMPUTER UTILIZATION FOR
ENGINEERING AND M & O JOB SHOP

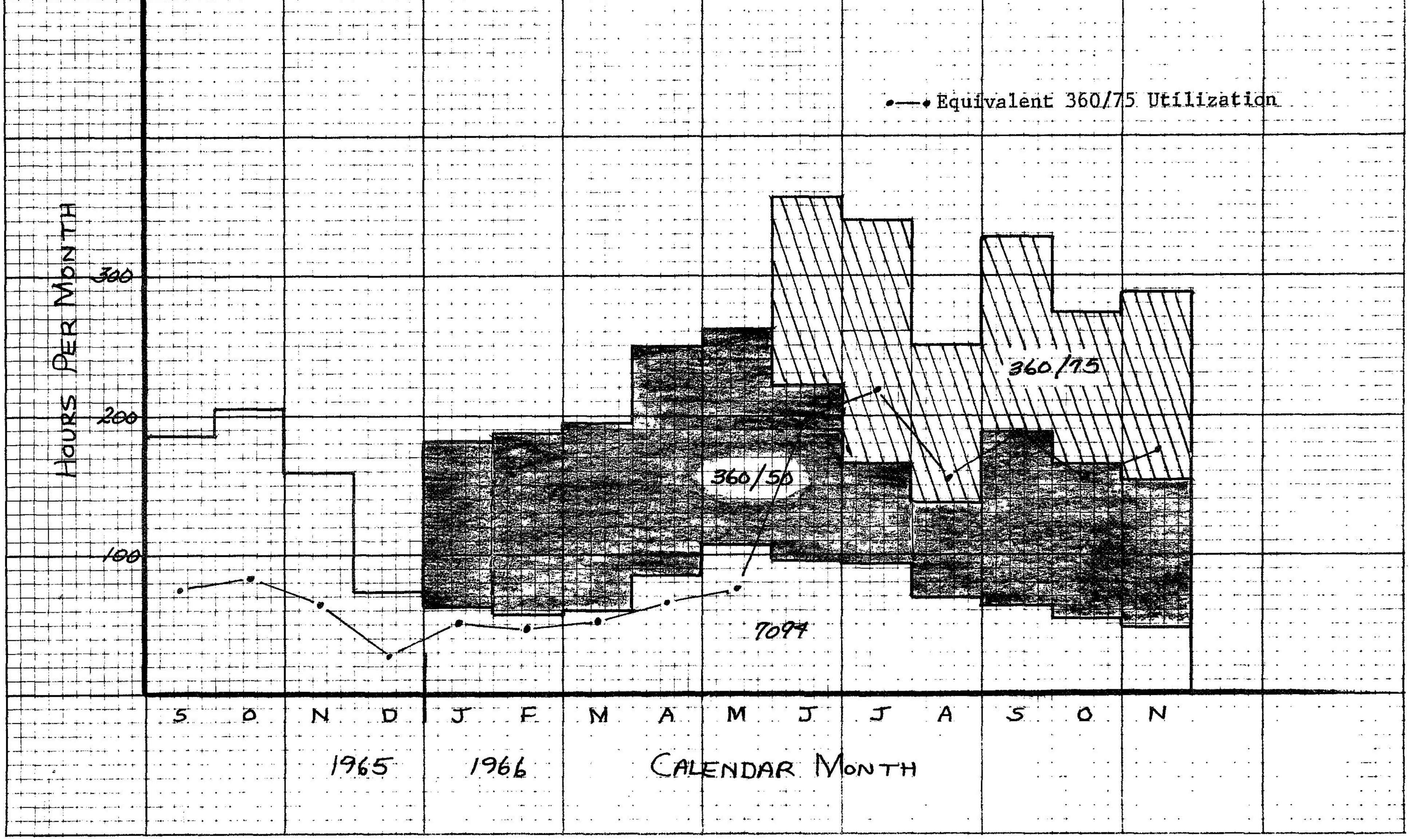


FIGURE A.4-9

COMPUTER UTILIZATION FOR
PROJECT MANAGEMENT & ADMINISTRATION

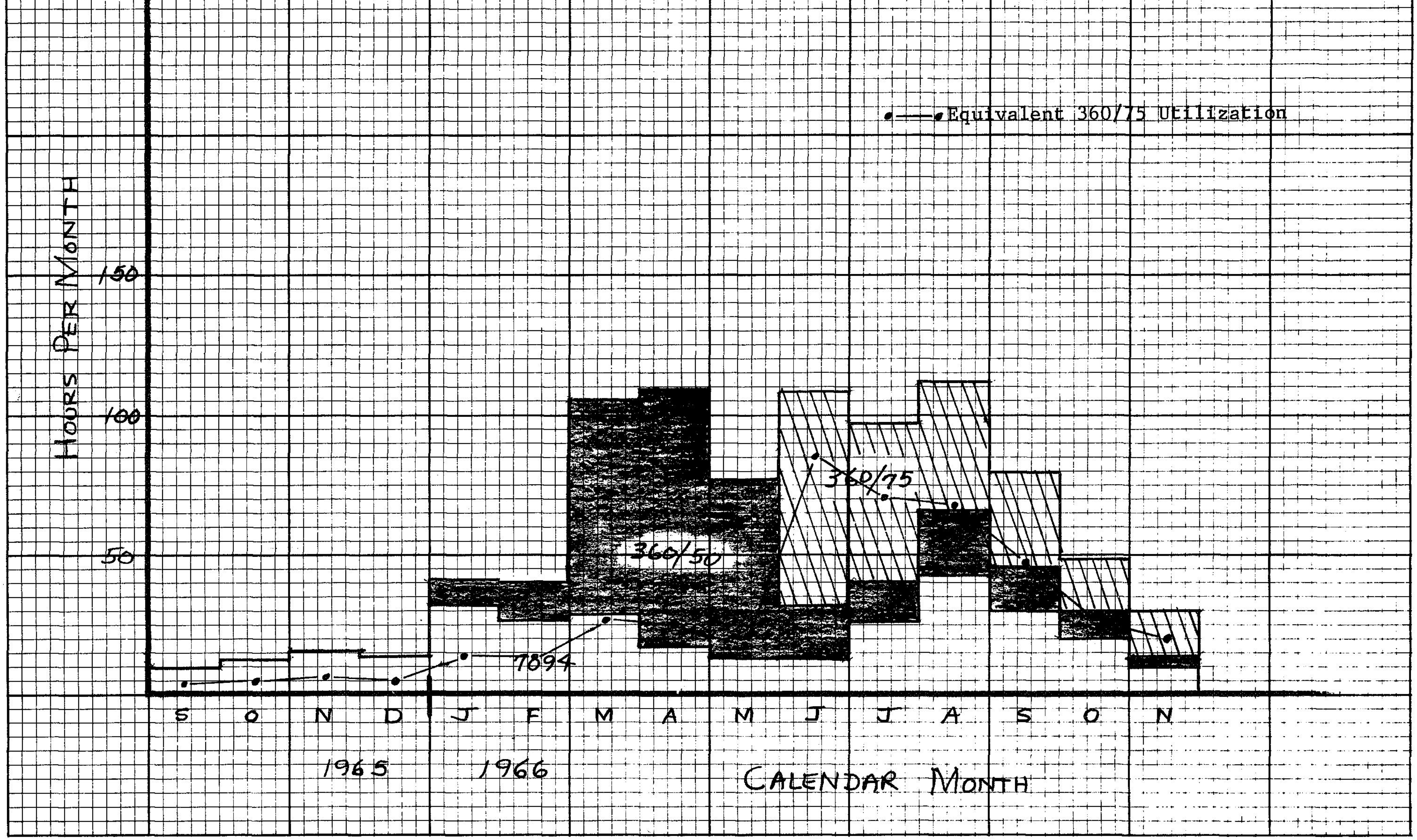
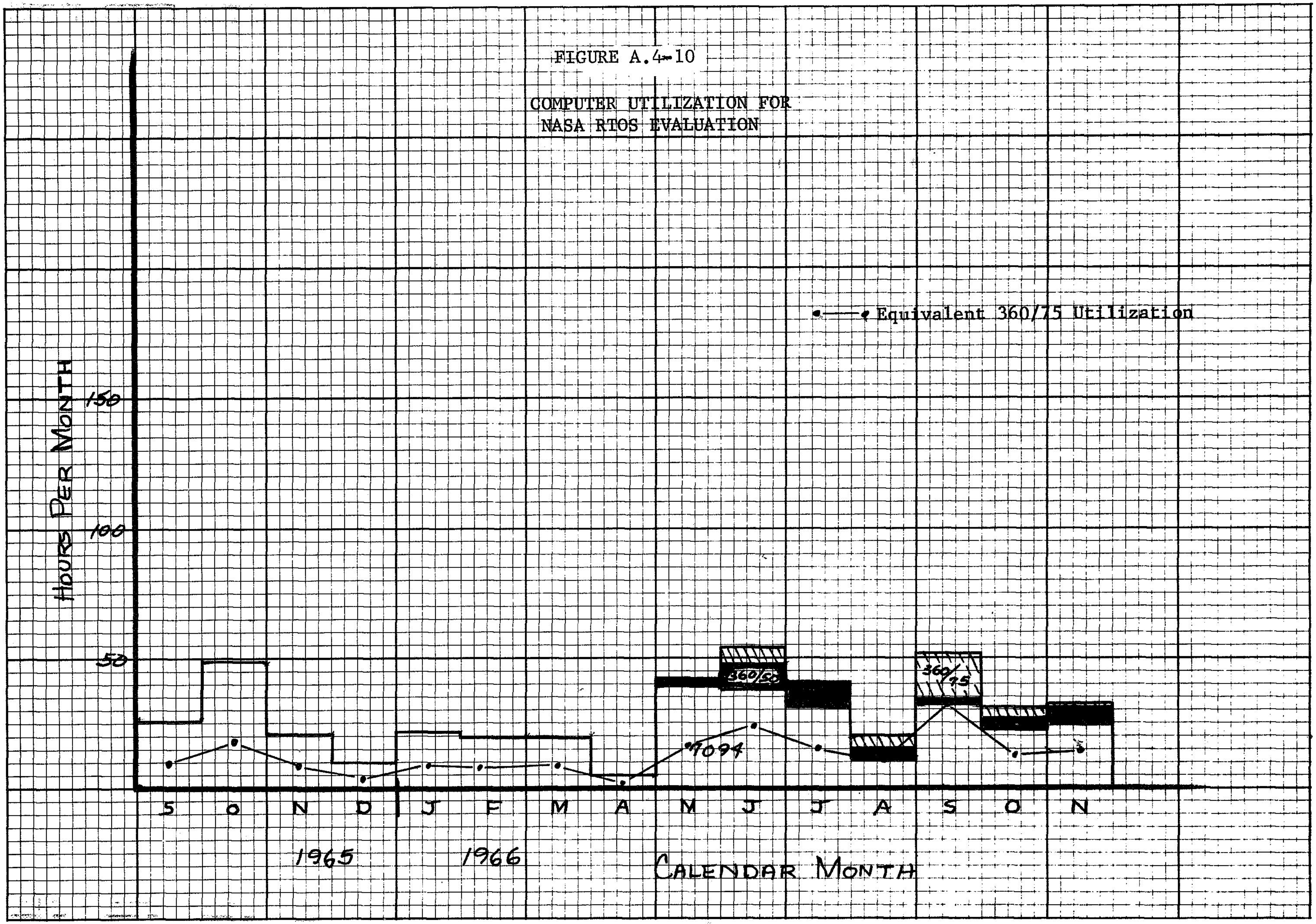


FIGURE A.4-10

COMPUTER UTILIZATION FOR
NASA RTOS EVALUATION



might be expected to grow in the future, it is uncertain to what extent it might, so a nominal thirty hours a month will be allocated to this user.

Support for the Computation and Analysis Division is indicated in Figure A.4-11. All of this support was given on 7094 systems. CAD has its own computers and time was given them on the 7094 systems for the most part as a low priority user to insure that time might otherwise go idle on the 7094 systems was used to advantage. No allocation will be made for this user in planning for the post-Apollo era. However, this does not intend to imply that CAD will not be allowed use of the systems but only that it will continue to be used as filler for otherwise idle periods.

In summary the three miscellaneous users identified in this section will require 255 hours per month.

Operational Support

Operational Support encompasses the real time applications of the system for conduct of missions, pad tests and the simulations which lead up to a mission. These latter include the launch-abort sims, sim net sims, orbit sims and the checkout of these simulations. Operational Support does not include the operation of the GSSC computer which is covered under the section titled "GSSC Program Development Support" above, nor the operational use of ORACT covered in "ORACT Development and Support."

In order to estimate the number of computer hours required in the post-Apollo era for operational support three variations from current experience must be accounted for. These are:

(a) Post-Apollo missions will be of longer duration.

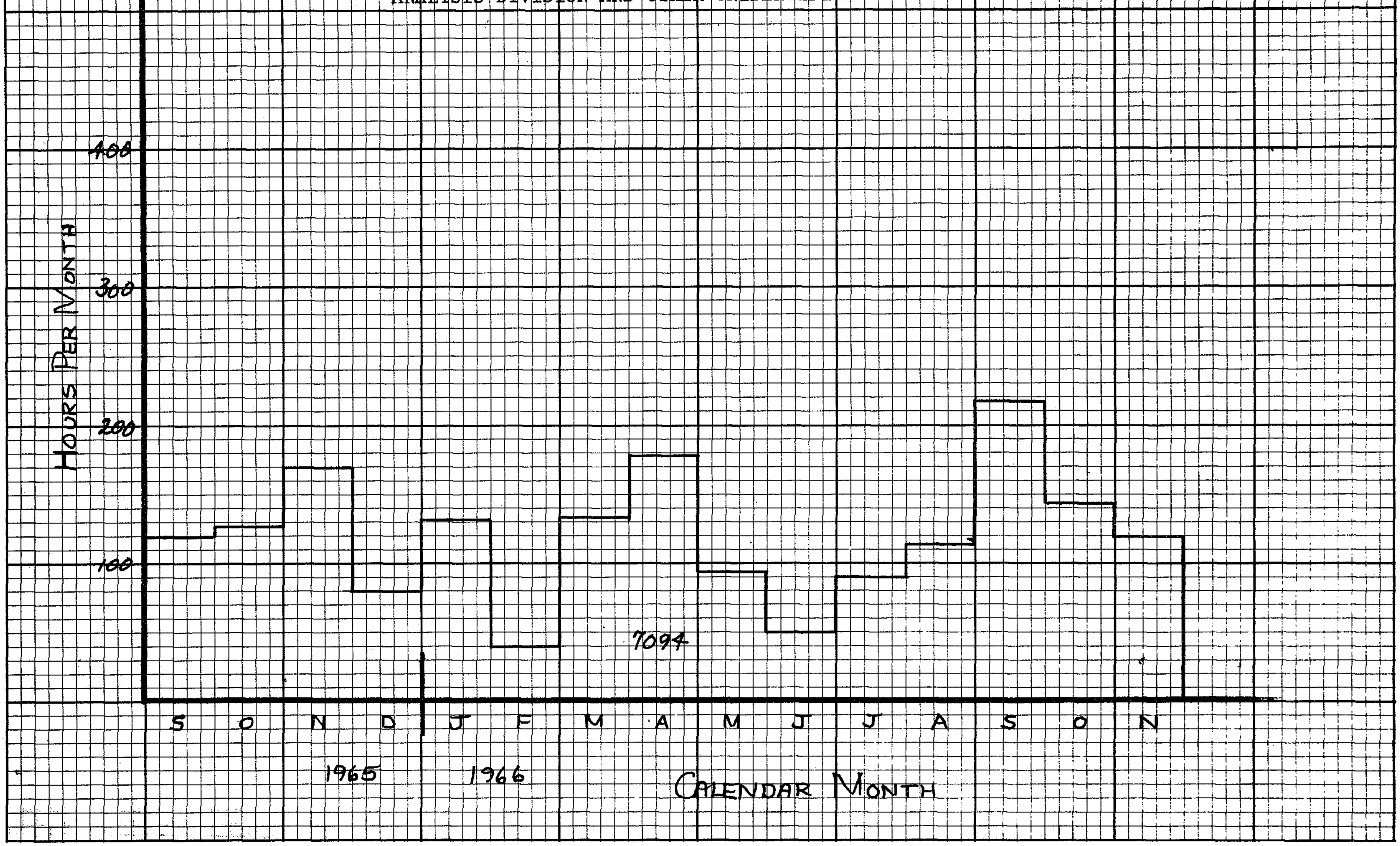
(b) Requirements for Dynamic Standby may be reduced to critical phase support only.

(c) The use of two or more functionally oriented machines to support post-Apollo missions will permit overlapping mission operations to be handled with the same number of machines as for a single operation.

The approach taken in this paper in estimating computer hour requirements for operational support of post-Apollo missions is to take the operational support data for the fifteen month sample interval and remove the time associated with the actual conduct of missions. This results in the number of hours required to prepare for the missions. This total preparation time is divided by the number of missions to obtain an average per mission. To this must later be added the number of hours required to support the longer duration post-Apollo missions for the various backup options and mission/functional system organizations.

FIGURE A.4-11

COMPUTER UTILIZATION FOR COMPUTATION AND ANALYSIS DIVISION AND OTHER UNIDENTIFIED NASA USERS



Computer Utilization for Operational Support is shown in Figure A.4-12. Peaks in activity occurred for the following reasons: December 1965, the fourteen day Gemini 7/6 Mission; February 1966, intense preparation for GT-8; June, July, August 1966, the close scheduling of GT-9, GT-10, GT-11 and AS-202 and AS-203. The total number of hours spent over the fifteen month interval was 8,667 of which 371 hours were spent in preparation for AS-204. Excluding AS-204 since it was not conducted in the sample interval leaves 8,296 hours. These operational support hours were expended on GT 7/6, GT-8, GT-9, GT-10, GT-11, GT-12, AS-201, AS-202 and AS-203. The direct mission support reckoned on the basis of an MOC and DSC from load program time to reentry was 1,593 computer hours. Subtracting these hours from the total spent on the nine missions gives 6,703 hours, or a preparation time of 745 hours per mission to support the simulations, simulation checkouts and the pad tests.

While three variations between post-Apollo and current experiences were noted above, the first two, longer duration and dynamic standby considerations, do not affect preparation time. The third, possible use of functionally oriented machines, will provide a capability to run some of the simulations and pad tests in conjunction with live missions thereby effecting some savings. On the other hand, if, for reasons of schedule, conflicting system requirements, or lack of confidence in the joint operation, it is not possible to run a given simulation or pad test in the same computer which is supporting a mission, then additional computer hours will be required to provide the extra functionally oriented computers. Faced with this dilemma, the operational support preparation time for the post-Apollo missions will be assumed to be the same (745 hours) as for the missions above).

The direct mission operational support is described in Appendix B.2 for the ML-65-3 and M(P)-2A schedules and in Appendix A.2 for the SR 500 models. In those appendices the significant variations in mission/functional organization and schedule densities are examined. Table A.4-IV below provides the number of computer hours per month required for the operational support leading up to the mission based on 745 hours per mission. To these must be added the corresponding numbers for direct mission support.

TABLE A.4-VI

COMPUTER HOUR REQUIREMENTS FOR PRE-MISSION OPERATIONAL SUPPORT

Density Mission/Year	Hours per month required on 360/75 Systems	Comments
7	434	
8	496	Avg. M(P)-2A yr. (8.4)
9	559	
10	621	Worst M(P)-2A Yr. (10)
11	682	Avg. ML-65-3 Yr. (11.4)
12	745	
13	807	Worst Case ML-65-3 Yr. (13)

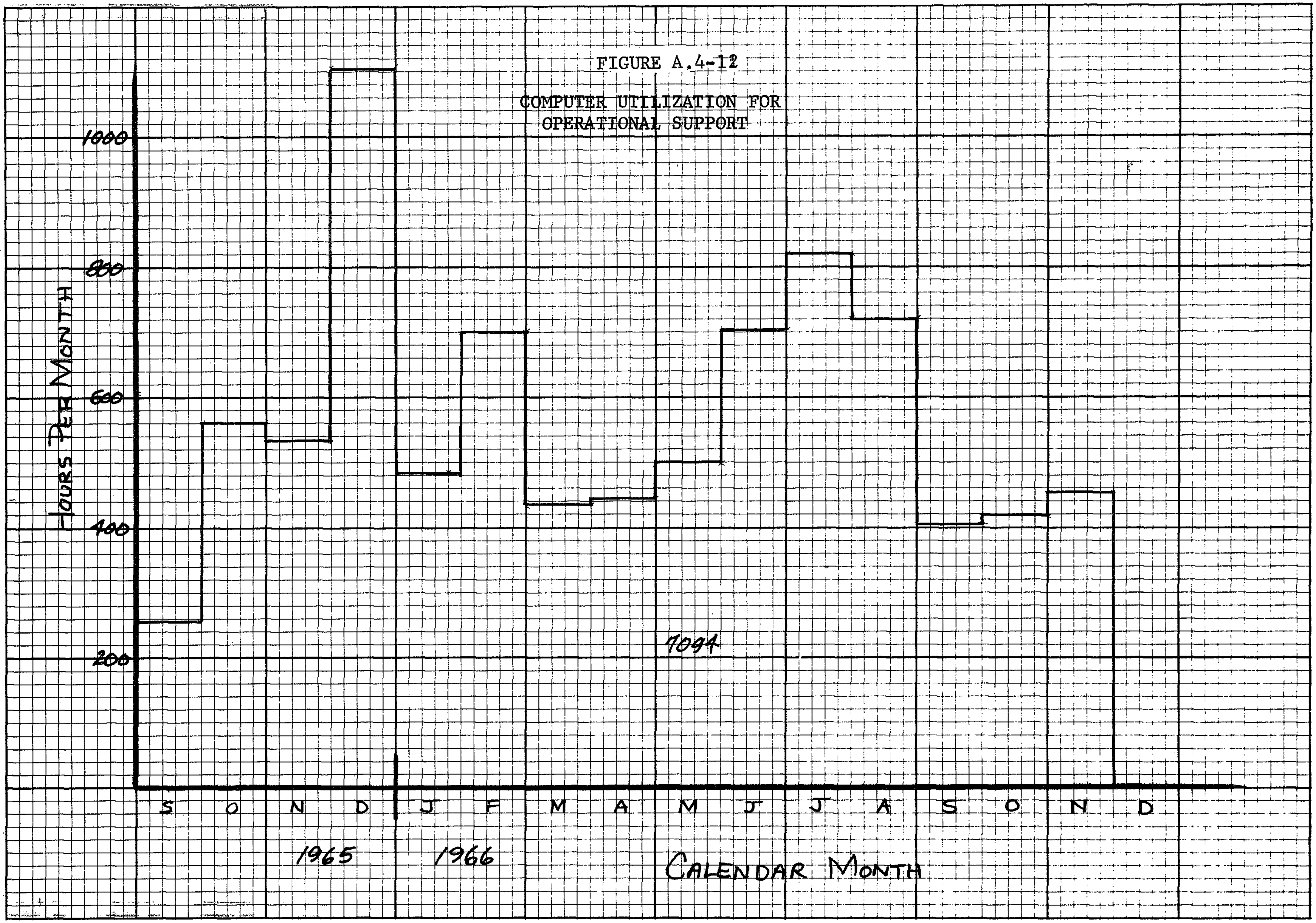


FIGURE A.4-12

COMPUTER UTILIZATION FOR OPERATIONAL SUPPORT

SUMMARY OF COMPUTER HOUR REQUIREMENTS

This section summarizes and combines all of the estimates developed in the above section (Computer Hours Estimators) and shows by a single example how the data might be used.

Computer hour requirements developed above were of two types:

(a) Requirements which did not vary with mission density. These include the RTOS development, Systems Analysis, Engineering, Computer Center Branch Support, M & O Job Shop and Project Administration (530 hours/month total).

(b) Requirements which varied with mission density. These include Mission Program Development, GSSC Development and Operational Support, Dynamic/Script Development, ORACT Development and Operational Support, and Operational Support preparation.

Within the second type a possible savings of 22% was identified for Mission, GSSC and Dynamic/Script through development of real time multi-job capability.

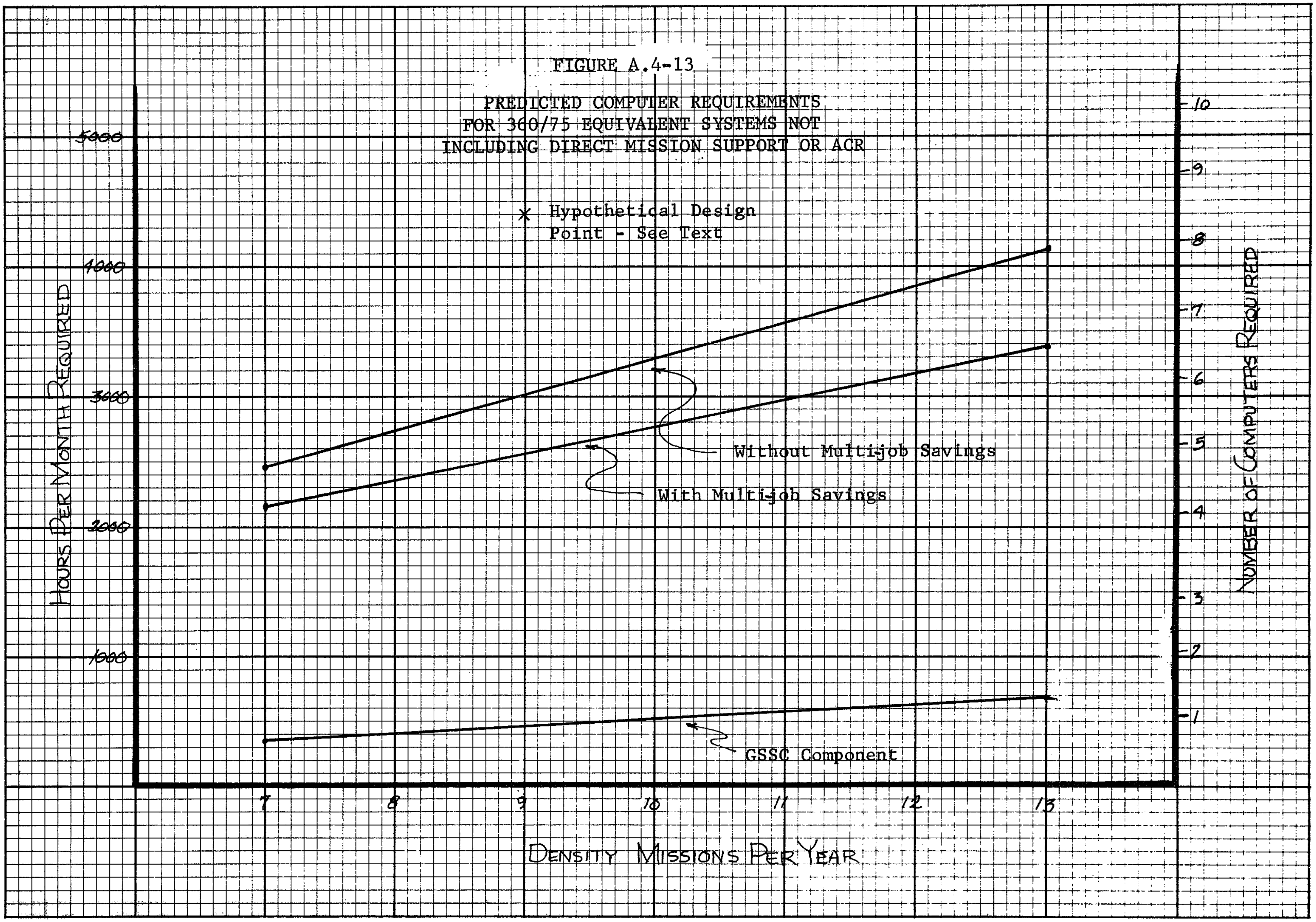
Figure A.4-13 presents the combined computer hour requirements in 360/75 equivalent hours both with and without multi-job savings. A third line at the bottom of the figure indicates the GSSC component of the total to permit consideration of the continued segregation of that system in Building 422. The scale at the right of the figure, number of computers required, is based on 525 productive hours per month (the remaining 195 hours being spent in preventive maintenance, machine down, idle, or reruns due to machine failure).

Two omissions should be kept in mind when using the figure. Hours for ACR development and operational support and the hours for direct mission operational support are not included. This latter time is defined as the time from loading the programs, nominally ten hours before launch, until re-entry.

Finally one might wish to consider systems produced by other manufacturers which provide equivalent capabilities. This might be done but only with less confidence in the results since other factors than the relative performance of the computers would enter the analysis. The number of computer hours required was based on experience with IBM as the major system programmer using IBM systems; changing the system programmer and/or the systems used could change the picture conceivably for better or for worse. Neither criticism nor praise is intended by this remark. The point which is intended to be made is that the prediction of computer hours is based on current experience with IBM, and predictions which do not involve change in computer systems or system programmer can be made with greater confidence.

FIGURE A.4-13

PREDICTED COMPUTER REQUIREMENTS
FOR 360/75 EQUIVALENT SYSTEMS NOT
INCLUDING DIRECT MISSION SUPPORT OR ACR



An Example of Using the Figure

Let us suppose that an analysis of a post-Apollo schedule has been made and it is determined that nine flights a year must be supported. (Post-Apollo flights are used instead of post-Apollo missions since a post-Apollo mission may be composed of several flights.) Being of a conservative nature the decision maker might choose not to bank on the multi-job savings but rather use this as an additional capacity to fall back on if needed. So choosing the upper line on the figure, 3000 hours per month is found. This includes the computer hour requirements for everything except direct mission operational support and the ACR. The hypothetical AAP schedule analysis also revealed that an average of 450 hours per month would be required for mission operations and since the particular data handling design calls for two computers on line at all times (one Telemetry machine and one integrated Trajectory/ACR machine) the 450 hours is doubled. Suppose also that ACR program development requires 500 hours per month. This brings the total up to 4400 hours per month indicated by the hypothetical design point in the figure, and represents, at 525 hour per month, 8.38 equivalent 360/75 systems. One might satisfy the requirement in several ways with IBM 360 systems: 9 Model 75 systems would provide extra capacity, 8 Model 75s and 2 Model 50 systems provide an equivalent of 8.40, or Model 65 systems might be substituted for some Model 75s at the rate of two Model 65s per Model 75 for job shop applications or on a one to one basis in real time applications if they fit the particular application. It is perhaps interesting to note that the GSSC component requires 470 hours per month or almost one computer's worth of time for this mission density.

Some Considerations Related to ACR Computer Hour Requirements

The Computer Hour Requirements associated with ACR are deliberately segregated in this section for two reasons.

(a) The form which ACR integration with RTCC will take has not been defined and this has a potentially large impact on the Computer Hour Requirements.

(b) A comprehensive analysis of ACR requirements has not been made (primarily due to lack of computer utilization data).

The ACR utilization experience may be summarized as follows: During the Gemini and early Apollo period the ACR computer was used almost full time for ACR support or development. There was not a large amount of ACR work done on other machines. These together would suggest that the ACR as currently implemented amounts to about one IBM 7094 computer full time.

The ACR computer is used for four different kinds of operations:

(a) Direct mission support

(b) Support of flight controller simulations

(c) Support of "in-house" simulations

(d) Program development and checkout

The first three of these are similar in that they are run in an operational or quasi-operational configuration; the current method of operation is to conduct these operational type runs in scheduled block time. The last category of usage, program development and checkout, can be performed in a job shop mode of operation.

Integration Alternatives

The form which ACR integration takes, could have a large influence on the number of computer hours required. Three different forms of integration will be discussed to emphasize the differences in computer hour requirements which could result.

1. Loose Integration

Under the concept of loose integration the RTCC supplies on of its computers to the ACR controllers and for a scheduled block of time the computer is used as an ACR machine only. The machine thus designated as the ACR is not called upon to do any jobs other than ACR jobs. The operation is basically same as the current way of doing business.

This concept of integration is the most expensive of the three forms of integration since all operations are scheduled in block time and no advantage can be taken of idle periods to do other than ACR jobs.

2. Integration with RTCC Job Shop

The second alternative is to integrate the operation of ACR into the RTCC Job Shop. Under this mode of operation ACR runs would be submitted for processing as high priority tasks within the Job Shop facility. These ACR jobs would compete for computer resources with other job shop runs with the end result that otherwise idle periods would be effectively used for other job shop work. The priority assigned to ACR jobs would essentially eliminate the possible undesirable response time impact of competing with other jobs. This involves a change in operations. The ACR controllers would probably not have the same amount of freedom to start, stop or modify the jobs as they are being run.

The advantages of this approach are the savings in computer hours effected by only paying for the hours used as compared with the block time scheduling approach in which one pays for all of the hours scheduled whether used to advantage or idle.

3. Integration into RTCC Trajectory Processing Element

The third alternative is only suited to RTCC system organizations in which there is a separate 360/75 for trajectory processing. Under this alternative the ACR programs would become a part of the total trajectory processing system, thereby taking advantage of the fact that the trajectory machine would be only lightly loaded from a real-time processing viewpoint except when certain on-call functions are initiated (differential corrections, command load generation, mission planning).

Under this last alternative there would not exist any separate requirement for operational support hours for ACR (what used to be ACR jobs now being part of the RTCCO. The only computer hour load associated with this type of integration would be the hours required for program development and checkout.

Estimated Computer Hour Requirements

In all of the above cases the relative savings apply to the three operational components of computer hour usage. The program development and checkout computer hour requirements are not clearly affected by the various alternatives for integration and can be assumed to be the same for all three.

Since there is no data on usage for the various components one can only make educated guesses about what the usage might have been over the last fifteen months.

Total Usage; 525 hours/month x 15 months	7875 hours
Direct Mission Support (actual mission time)	-796
Flight Controllers Sims; 100 hrs/mission x 9 missions	-900
"In House" Sim support; 100 hrs/mission x 9 missions	-900
REMAINDER	5279 hours

The remainder of 5279 hours was assumed to be used for program development and checkout; on the fifteen month basis it amounts to 352 hours/month.

In order to translate these numbers into equivalent hours on a 360/75 system several adjustments should be made. One must adjust the mission time to the longer mission durations of the post-Apollo flights. Adjustments of computer hours by the differences in capability between the 7094 and 360/75 systems should be made for all job shop work loads. Adjustment to a mission density of eight flights per year is made for example purposes, to bring the flight density into the range used in the previous sections of this paper. Conversion of block time hours to the equivalent job shop hours for the job shop integration was accomplished by noting that the ACR was busy, for missions GT-10 through GT-12 (See MPAD Flight Analysis Branch reports on ACR Support for Gemini missions and simulations), only about 40% of the time on a 7094; this converts to a 16% busy on a 360/75 when the 2.5 speed advantage is applied. The following table indicates a summary of the 350/75 computer hour requirements at a flight density of eight flights per year.

	Loose Integration	Job Shop Integration	TRAJ Integration
Direct Mission Support (Prime Model)	444 hr/mo	71 hr/mo	0 hr/mo
Flight Controller Sims	67	10	0
"In House" Sims	67	10	0
Program Development and Checkout	141	141	141
TOTALS	719	232	141

It should be noted that computer hour requirements for the job shop integration case are very sensitive to the estimate of how heavy the processing load for ACR really is. In this example it was assumed that 16% of a 360/75 was sufficient to handle the ACR load. If the load amounts to 50% of a 360/75, the total would be 431 hours per month instead of 233. Also, if a 360/75 were 50% busy with ACR jobs, it is doubtful that it would be desirable to integrate ACR into a trajectory machine.

There are two other factors which contribute to the magnitude of the ACR job which have not been addressed in this section, namely: the extent to which ACR programs which are redundant with RTCC programs will be deleted, and the question of how much Program Development and Checkout requirements may change due to more or less extensive development and checkout of the programs prior to incorporation as ACR programs.

In conclusion it has been shown that there is a wide variation possible in ACR computer hour requirements depending on how it is integrated. A firm estimate of ACR computer hour requirements cannot be made until a method of integration is settled upon.

APPENDIX A.5

EVALUATION CRITERIA

The evaluation criteria presented in Table A.5-I of this appendix have been developed in direct support of the review procedure described in Appendix A.1. The application of these criteria to Augmentation II design approach alternative(s) constitutes the final step of the review process. Preceding steps in the review process assess the ability of a particular Augmentation II alternative to satisfy requirements which are directly derivative from SR 500. These evaluation criteria, on the other hand, are not directly related to flight control needs as expressed in SR 500. They support comparative evaluation of alternatives primarily from a design or system engineering viewpoint by identifying system features or characteristics considered desirable for any computer-based system complex. They include general items such as growth potential, flexibility, ease of reconfiguration, etc. Because criteria of a general nature may not be successfully applied to a particular evaluation problem until further defined, those aspects considered specifically pertinent to the Augmentation II evaluation have been identified.

Table A.5-I criteria, admittedly overlapping in certain cases, reflect the emphasis of this review process on system organization and sizing as first order design issues at the design approach stage of Augmentation II definition. In addition, these criteria have been tailored to the expected level of detail for the alternatives to be reviewed; only criteria considered applicable at an overall system level have been included. For example, criteria unique to review of display/control alternatives do not appear but will be reflected as part of the display/control review itself.

The set of evaluation criteria presented here represents a judgment as to which criteria will be useful during the process of selecting a design approach alternative. During the review process itself, however, a reassessment of the usefulness of each criterion will be made. The nature of the alternatives to be reviewed will in part determine the applicability of these criteria.

It is envisioned that review results will generally be expressed in qualitative and comparative terms such as least, lesser, most, limited, adequate, extensive, etc. It is conceivable that the most meaningful expression of evaluation results for certain criteria may be by data type (e.g., TLM vs. TRAJ) and/or by MCC-H system (e.g., CCATS vs. RTCC). The final process of applying the review results based on these criteria to the selection of a preferred alternative will involve a subjective weighing of the results based primarily on engineering judgment.

TABLE A.5-I

EVALUATION CRITERIA

In order to clarify the meaning of certain criteria (or aspects thereof), supporting information is provided in the "Comments/Examples" column. Other criteria are considered self-explanatory.

CRITERIA	COMMENTS/EXAMPLES
<u>Cost</u>	
For Hardware Additions/ Modifications	
For Software System Reorganization	Costs for "Software System Reorganization" would include, for example, those associated with "splitting" the present mission-oriented software packages into separate TLM and TRAJ packages for assignment to different computing elements. For software additions/modifications which are insensitive to the system organization but are required by the mission characteristics, costs may be considered constant for all alternatives; such costs, therefore, are not of interest for comparative evaluation.
<u>Growth Potential</u>	
% CPU Time Available for Growth	The "% CPU Time Used" aspect of computing capacity has been singled out as particularly significant.
Ability to Accommodate Additional Computer Hour Demands	Purely concerned with the degree to which available computer hours exceed the number associated with satisfying known requirements.
<u>Flexibility</u>	
Insensitivity to the Flight Controller Organizational Structure for Mission Support	This aspect views the Flight Control organizational structure in terms of the allocation of mission control responsibility between different operational areas. Concern centers around questions such as, "Will the proposed system easily adapt to a flight control structure consisting of functionally-oriented rather than mission-oriented control areas? Will the system support a larger number of independent control areas without costly modification?"

Compatibility with Different Schemes for Allocating Functions Between Processing Elements	The aspect causes one to address, for example, whether a proposed configuration involving a mission-oriented allocation of tasks to different computing elements will readily adapt to a functionally-oriented allocation of tasks if desired.

<u>Ease of Reconfiguration/Testing</u>

Independence Between Different System Elements for the Conduct of Checkout/Testing	This aspect addresses questions such as, "Does display system checkout require RTCC support?"
Independence Between Different Software Elements for Program Development and Checkout (These software elements may be in the same or different computing elements.)	This aspect evidences concern, for example, with the ability to make and checkout software changes in a certain portion of the software system without requiring that the operation of other portions of the software system be totally re-verified.
Ability to Make Mission-By-Mission Changes by Software Reconfiguration Only - Display Reconfiguration - Other	

<u>Ease of Implementation</u>

Ability to Maintain Continuity of Flight Support Operations	This aspect involves consideration, for example, of the ability to "phase in" new or additional hardware without causing an unacceptable interruption of service.
Confidence in the Ability to Meet Implementation Schedules	Treatment of this aspect must generally be constrained to gross considerations such as how the ability to meet schedules varies as a function of the degree of reprogramming required in support of a particular configuration.

<u>Reliability</u>

Sensitivity to Single Point Failures	This aspect requires, as an example, consideration for various alternatives of the degree of mission control capability remaining once a CCATS processor is no longer available.
Ability to Interchange Computing Elements	This aspect reflects, in a qualitative manner, the advantage of interchangeable processors in terms of permitting completely flexible assignment of resources to tasks on a priority basis. (Could have been considered an aspect of flexibility.)

APPENDIX B.1

BACKGROUND AND GENERAL DESCRIPTION

INTRODUCTION

In addition to developing the review process described in Appendix A, MITRE has conducted an independent investigation of certain Augmentation II design issues. This investigation was undertaken as a complement to the NASA design effort, offering the potential advantages of a different viewpoint, and as a means of enhancing MITRE's review capability by forcing a direct encounter with Augmentation II design considerations. The purpose of this appendix is to provide an understanding of the MITRE design effort in terms of its general orientation and of a specific design process which has been developed. Subsequent appendices are devoted to describing the detailed application of the design process which has evolved and to discussing the results achieved.

ORIENTATION OF THE DESIGN EFFORT

Two aspects of the Augmentation II design problem impart a specific orientation to MITRE's approach to the overall design effort.

Emphasis on Costs vs. Requirements

The most significant single feature of the design effort described herein is related to the nature of the environment in which Augmentation II design is being accomplished. In particular, two characteristics of this environment may be readily identified as follows:

Cost is of prime importance.

Post-Apollo program plans upon which requirements have been based are less than firm.

Considering these two factors together, it may be concluded that consideration of possible tradeoffs between costs and requirements is desirable. To support the decision-maker in considering such tradeoffs, design results must be provided in a form which clearly relates system costs to the requirements "designed against" throughout a selected range of such requirements. Given such a spectrum of costs vs. requirements, the decision-maker may then select alternatives based on an explicit recognition of the relative costs involved in providing different degrees of mission support capability. Based on this reasoning, development of design results which clearly indicate the sensitivity of costs to requirements has been adopted as a prime objective of the MITRE effort.

Regarding the actual pursuit of the cost vs. requirements sensitivity question, development of the specific process described below has involved certain steps which would be common to any such sensitivity analysis: identification of those requirements which may be treated as "variables" and which significantly impact upon system cost, formulation of tools and techniques for quantifying the cost impact of the selected requirements, and generation of design results throughout a reasonable range of requirements. These steps are discussed in more detail below. Although the incorporation of system improvements not directly related to the satisfaction of requirements is a legitimate objective of augmentation design, this objective has been considered secondary to the objective of meeting increased operational demands. It is implied, therefore, that the incorporation of certain system improvements is not considered a design requirement. The ability to incorporate such improvements, however, would be considered in the final selection between operationally-oriented alternatives.

Identification of RTCC Organization as Central Design Issue

Based on an initial look at the overall Augmentation II design problem, RTCC organization and the associated sizing were identified as central design issues which could be fruitfully addressed - from a cost vs. requirements sensitivity viewpoint - by the available manpower resources. System "organization" as used herein refers to the allocation of functions between computing elements; "sizing" as used herein refers to consideration both of instantaneous loading for individual computing elements (% CPU time used) and of computer hour utilization for the entire RTCC complex. Those factors which led to the stated emphasis on RTCC design questions are discussed briefly below. They support an understanding of the system context in which the MITRE design results should be viewed.

Consideration of Display/Control Issues

Several factors contributed to the conclusion that the Display/Control design might better be treated as an essentially independent issue at a relatively detailed level than as a problem lending itself to an investigation of costs vs. requirements at a gross level. These were:

(a) For non-TV functions, equipment types which are already in service will be employed. Augmentation design consists simply of responding to increased quantitative requirements; no alternatives at the design approach level need be considered.

(b) Once one accepts the concept of digital TV and defines a division of functions between the RTCC and the D/TV systems corresponding to the division presently employed, a design approach has been identified. Design issues remain only at a more detailed level when addressing issues of sizing, timing, tradeoffs between stored-program processors and wired-logic, etc.

(c) Although significant design issues related to interfacing the RTCC with the Display/Control (D/C) System will arise and will be influenced by the RTCC system organization, it appears that reasonable solutions exist to the interface problems associated with any meaningful RTCC system configuration. (Examples of possible problems - VSM control by more than one RTCC computing element when a mix of all digital and charactron-type D/TV channels still exists, delivering CIM inputs to more than one RTCC computing element. Examples of possible solutions - hardware modifications to VSM control interface, display sharing via 2911's, etc.)

(d) Straightforward relationships exist between display costs and display requirements (costs per D/TV channel, costs per console, etc.). A more sophisticated analysis of costs vs. requirements, therefore, is not warranted.

Consideration of CCATS and RTCC/CCATS Interrelationships

Defining the MCC-H Data Handling System as the combination of CCATS and the RTCC (design of simulation system being accomplished separately), a first order question is whether the present allocation of functions* between these two computing complexes should be maintained for post-Apollo support. This question was addressed by using the functional block diagram presented in Appendix A.2 ("MCC-H Data Handling Functions," Figure A.2-1) as a basis for defining functional allocation alternatives and by imposing the following criteria when considering such alternatives:

> Maximize the use of capabilities already provided in the form of software or hardware. (Oriented toward minimizing cost.)
>
> Limit CCATS software sensitivity to mission-by-mission changes in such a way that tables and program parameters, but not program logic, may be affected. (Oriented toward maintaining CCATS as a stable switching device common to all data flow between the MCC-H and the external world.)

It was concluded that the present division of functions should be maintained, possible exceptions being of too minor a nature to be considered significant at the design approach level of Augmentation II. This conclusion permits one to consider the RTCC and CCATS design problems independently. (Recognizing, of course, that present RTCC/CCATS interface techniques are sufficiently flexible to support any reasonable combination of system organizations within each of the two computing complexes.)

An additional factor indicated that the CCATS design might best be treated in the same manner as previously described for the D/C System - as an essentially independent issue at a detailed design level rather than as a problem lending itself to cost vs. requirements sensitivity analysis at a gross level.

Assuming that a single 494 processor may successfully accommodate the post-Apollo, multi-mission equivalent of the processing loads being handled by a single 494 in the present CCATS configuration, no alternative CCATS organizations would appear to offer the possibility of "buying" more mission support capability with the same processing resources. Design issues exist, of course, at a more detailed level. (Note that sizing data of a preliminary nature accumulated to date indicates the following: from a % CPU time used viewpoint, a single 494 may handle a multi-mission post-Apollo load; problems may exist in terms of being able to successfully complete all data transfers under worst-case traffic conditions, but possible solutions exist within the context of the present CCATS system organization; the present complement of three 494's would appear, based on limited experience, to provide computer hour support which is adequate.)

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* "Present" as used here includes "as planned for the near-term." As a result, the centralization of responsibility for all digital display driving within CCATS is considered to be a feature of the "present" system.

Consideration of the RTCC Design Question

All of the above concluded, in effect, that design approaches of a reasonable nature had been established for the D/C and CCATS Systems, that questions still outstanding in these two system areas must be addressed at a relatively detailed level of design and that sufficient interface capabilities exist to insure successful integration of the final D/C and CCATS configurations into a total system context. The RTCC organization question and the related sizing issues, on the other hand, were singled out for particular attention because -

(a) The design approach question for the RTCC had not been resolved. Moreover, it was recognized that alternative RTCC system organizations possessed different degrees of merit in terms of the mission support capability purchased per dollar, ease of program development and checkout, etc.

(b) Sizing and, therefore, costs of alternative RTCC system organizations may be shown to be particularly sensitive to certain requirements. The RTCC design question, then, lends itself to an investigation of costs vs. requirements. (Discussed further below.)

(c) RTCC costs constitute a large proportion of total MCC-H system costs. The sensitivity of costs to requirements, therefore, warrants careful consideration.

Note that the above discussion of investigating alternative RTCC system organizations within a cost vs. requirements context implies generating design results at a relatively gross level. As decribed below, the design effort described herein produces an end product in the form of the numbers and types of computing elements required to support a particular set of requirements (e.g., four 360-75's and two 360-50's required to support SR 500 Interim Model # X).

Resulting Overall Objective

The two aspects discussed above of MITRE's approach to Augmentation II design - an emphasis on costs vs. requirements and identification of the RTCC organization question (and associated sizing) as the central design issue - lead to the following overall direction:

> Investigate the sensitivity of RTCC System costs to requirements while at the same time considering alternative RTCC System organizations. Objective: A spectrum of costs vs. requirements which explicitly relates RTCC System costs to requirements and which, for a given set of requirements, indicates the most favorable RTCC organization alternative from a cost viewpoint.

The emphasis on cost inherent in the objective stated above does not, of course, preclude the introduction of selection criteria other than cost during the final decision-making process. This emphasis is intended to imply, however, that cost data should be made available before alternatives are eliminated based on other criteria.

GENERAL APPROACH

The objective of providing a spectrum of cost vs. requirements has been approached by identifying those requirements to be treated as variables; identifying the particular RTCC organization alternatives to be considered; and, finally, by defining a design process which reflects the interaction between costs, requirements and RTCC organization alternatives.

When dealing with requirements, post-Apollo program plans constitute the starting point. Within the Augmentation II environment, these appear either as reference planning schedules or as models considered to be representative of these schedules. Both the schedules and models have been analyzed to determine those characteristics which are significant to the system designer, and, in particular, are significant to the level of design being accomplished - the numbers and types of RTCC machines in this case. Results of such an analysis show that any model or schedule may be reduced to four primary characteristics: the vehicle configurations involved, the launch intervals between successive flights, flight duration and the number of flights to be flown within a given period of time (flight density). These characteristics may be viewed as initiating a flow between requirements and design results. For example, the numbers and types of vehicles to be supported at any given time is determined by the vehicle complements for individual flights and the degree of overlap between flights as dictated by launch intervals and flight duration. This vehicle support requirement, in turn, generates a processing load which must be accommodated by the RTCC machine complement. As another example, a flight density is associated with a computer hour "workload" for mission preparation activities which must be supported within a fixed period of time. This "workload," in turn, converts to a computer hour requirement. Consideration of this kind of flow between requirements and computing resources has permitted identification of those requirements which are significant from a design viewpoint. These have been considered as variables in the sense that different "values" for these are derivative from different schedules or models.

In addition to requirements which are directly derivative from the models or schedules, other requirements reflect flight controller decisions on the manner in which a given model or schedule should be supported. The specification of dynamic standby operation for critical phases is an example of such a requirement; it is related to the models and schedules, but is not directly derivative therefrom. Requirements of this type may be treated as variables if different options exist which are operationally legitimate.

The term "requirements variable" has been coined to refer to those requirements which meet the criteria implied above: they may be treated as variables and they significantly affect RTCC system design and associated costs. Six requirements variables are identified in subsequent paragraphs (including those provided above as examples). Their values may be used to generate the spectrum of all combinations of requirements for which design results should be developed. In particular, a spectrum of 115 requirements combinations is formulated in Appendix B.3.

The number of RTCC organization alternatives to be considered constitutes the other important dimension of this design problem; eight (8) such alternatives are subsequently identified. Design results are expressed as the numbers and types of RTCC machines (and associated costs) required to satisfy a particular set of requirements with a particular RTCC organization. In summary, therefore, all which follows in this and subsequent appendices may be viewed as contributing to the definition of eight (8) RTCC configurations for each of 115 different sets of requirements where the design process facilitates the translation of requirements into quantitative design results.

IDENTIFICATION OF REQUIREMENTS VARIABLES

Table B.1-I delineates the six requirements variables selected for purposes of this design effort. Each of two SR 500 Models and the two most current reference planning schedules have been used to provide, as indicated, its own set of values for certain requirements variables. Each of these is considered to be of design interest as follows:

> <u>SR 500 Prime Model</u> - of interest as NASA's design goal and as a "recognized" worst case from a simultaneous vehicle support viewpoint.
>
> <u>SR 500 Interim Model 3</u> - of interest as representing a realistic minimum set of requirements from a simultaneous vehicle support viewpoint.
>
> <u>M(P)-2A</u> - of interest as the most current statement of total program plans for the post-Apollo era of manned spaceflight.
>
> <u>ML-65-3</u> - of interest as a "recognized" worst case from a flight density viewpoint.

As indicated, values for three of the six requirements variables are directly derivative from and uniquely dependent on the particular model or schedule of interest. Specific derived values are compiled in Appendix B.3. Values for other requirements variables are directly stated because they are essentially independent of the model or schedule under consideration. Exceptions to this independence and the resulting impact upon the design process are discussed in Appendix B.3.

The design significance of each requirements variable is discussed specifically in subsequent paragraphs. In more general terms, however, each variable impacts upon the RTCC design as follows:

(a) The number of concurrent operations, the number of simultaneous critical phases and the type of backup for critical phases combine to dictate the number of computing elements required to provide operational support at any given time when adopting a particular organizational scheme. For example, the number of concurrent operations may be equated to the number of required Mission Operational Computers (MOC) and Simulated Operational Computers (SOC) when dealing with a standalone system organization.

(b) The number of vehicles requiring simultaneous support dictates the processing load imposed on the various computing elements in the RTCC. Evaluation of this load requires a definition of the allocation of functions between such computing elements.

TABLE B.1-I

REQUIREMENTS VARIABLES

REQUIREMENTS VARIABLE	VALUES TO BE USED
Number of Concurrent Operations[a]	2, 3, or 4
Number of Simultaneous Critical Phases	1 or 2[b]
Type of Backup for Critical Phases	Dynamic Standby or Startup/Startover[c]
Vehicles Requiring Simultaneous Support[d]	Derivative from each model and schedule
Flight Density (Flights/Year)[e]	"
Computer Utilization for Support of Actual Missions (Hours/Month)[f]	"

EXPLANATORY COMMENTS:

[a]"Operations" refer to the conduct of actual missions, simulated missions, or pad support.

[b]A special value of "none" for the number of simultaneous critical phases is discussed in Appendix B.3 as legitimate only when concurrent with simulations or pad support operations which may be sacrificed in case of contigencies.

[c]Startup/Startover Backup implies that backup machines are available on call but are employed for non-mission processing until required to assume an operational role.

[d]A specification of the "Vehicles Requiring Simultaneous Support" includes the numbers and types of vehicles for which telemetry monitoring must be performed and the number of vehicle combinations for which trajectory processing must be performed (either in launch or associated with high or low speed tracking inputs).

[e]Flight density rather than mission density is employed as a requirements variable. It may be readily derived from each model and schedule.

[f]Values assigned to the "Computer Utilization for Support of Actual Missions" will reflect mission and flight duration.

(c) Flight density dictates the level of mission preparation activity requiring computer hour support within a given period of time and, as such, impacts upon the total computer hour requirements for the RTCC system. The number of computer hours utilized for support of actual missions constitute the remaining computer hour demands. (Computer hours devoted to support of actual missions are not available for activities of a preparatory nature such as program development and checkout, ORACT, etc.)

Note that the differences between support requirements for Apollo and the analogous requirements for post-Apollo are of a quantitative rather than a qualitative nature and, therefore, that Augmentation II design should be viewed primarily as a sizing effort.

IDENTIFICATION OF RTCC ORGANIZATION ALTERNATIVES

Different schemes for allocating functions within the RTCC may be viewed either as mission-oriented, function-oriented, or as some hybrid combination of the two. A mission-oriented scheme may be equated to the present standalone concept. A function-oriented scheme, on the other hand, involves the division of all processing tasks into functional groupings and assignment of each functional grouping to a single computing element which performs the assigned processing functions for as many missions or flights as require support. Support of multiple missions by a configuration consisting only of a telemetry processing element and a trajectory processing element (assuming command and mission planning functions are included within the trajectory grouping) is an example of a function-oriented system design. A hybrid mission and function-oriented organization scheme might take, for example, the following form: support of multiple missions with functionally-oriented computing elements with selected critical phases treated as exceptions by being given mission-oriented computing support (e.g., present Data Handling Group alternative for RTCC design).

The above discussion is of a general nature. The eight (8) functional allocation alternatives actually considered during this RTCC design effort are listed in Table B.1-II. The inclusion of the present standalone concept should be self-explanatory. The appearance of the specific set of seven other alternatives, however, deserves some comment. As background, an analysis of RTCC functions (as represented in Figure A.2-1, Appendix A.2) led to the conclusion that only three major functional groupings exist as reasonably independent entities: telemetry processing, trajectory processing (defined herein to include command load generation and mission planning functions due to their dependence on the trajectory processing data base), and display processing. Attempts to identify other major groupings either violated the logical desire to minimize the degree of interdependence between functions assigned to different computing elements or resulted in a completely unbalanced distribution of the processing load. Note also that the display grouping may be reasonably split into its trajectory and telemetry components with the components being absorbed by the appropriate non-display computing elements, resulting in a two-part division between telemetry and trajectory processing.

The above discussion explains the presence of Alternatives two and three in Table B.1-II. Alternative 4 combines trajectory and display processing functions in a single computing element. Because preliminary loading

Table B.1-II

RTCC SYSTEM ORGANIZATION ALTERNATIVES

ALTERNATIVE	ID
Pure Mission-Oriented (Standalone)[a]	1
Pure Function-Oriented:	
TLM-TRJ[b] or	2
TLM-TRJ-DISP[c] or	3
TLM-TRJ/DISP[d]	4
Launch/Function Hybrids:	
TLM-TRJ-Launch[b]	5
TLM-TRJ-DISP-Launch[c]	6
TLM-TRJ/DISP-Launch[d]	7
Mission/Display Hybrid: Mission-oriented for non-display processing; function-oriented for display processing.[e]	8

NOTES: [a] The adopted definition of a single mission is such that multiple flights may be included if these are in support of common mission objectives. As an example, using SR 500 terminology, all three flights of an "Earth Orbit Large" combination are considered as a single mission while the two flights of a "Lunar Large" combination, despite the small launch interval, are viewed as separate missions. (See Appendix B.2 for a discussion of this definition as applied to the reference planning schedules.)

[b] TLM and TRJ computing elements each perform their related display processing functions.

[c] All display functions are performed in a single computing element; TLM and TRJ elements do not perform display functions.

[d] TRJ and DISP functions are combined in a single element. In this case, "DISP" includes display functions related to both TLM and TRJ processing; TLM element, therefore, does no display processing.

[e] Display functions for all missions are centralized in a single computing element. Mission-oriented elements perform all other functions.

results indicate that the demands on CPU time for real-time telemetry processing are far greater than those associated with real-time trajectory processing, a combination of trajectory and display processing offers the possibility of a more evenly distributed processing load.

Alternatives 5, 6, and 7, designated as "Phase/Function Hybrids," are identical to alternatives 2 - 4, respectively, with the exception that launch is treated as a special case and is supported by a mission-oriented computing element. In particular, alternative 5 corresponds roughly to the approach presently being proposed by the Augmentation II Data Handling Group. Display processing is a significant portion of the total processing load for a standalone computing element. Transfer of this load component to a centralized display processor might, therefore, permit the introduction of mission-oriented machines smaller than a 360/75. Alternative 8, therefore, is included only to investigate possible savings associated with the use of smaller machines.

In summary, the eight RTCC organization alternatives represented in Table B.1-1 constitute the total complement of such alternatives to be evaluated within the scope of this design effort. No other reasonable alternatives have been identified.

MITRE DESIGN PROCESS

All of the preceding may be considered preparatory to the actual task of generating design results: requirements variables have been identified in support of the emphasis on costs vs requirements sensitivity analysis; RTCC organization alternatives have been identified in support of a comprehensive investigation of possible design approaches. This section describes a specific design process which facilitates consideration of all RTCC organization alternatives and whose results reflect the interaction between requirements and RTCC system costs. A relatively highly structured process is described herein; such a process permits the efficient generation of design results for the many possible combinations of requirements and organizational schemes.

Constraints and Assumptions

Certain constraints and assumptions are inherent to the process to be described. Because loading and utilization data in support of system sizing is available only for IBM equipments, only Series 360 machines are considered for the sizing process. This constraint can be removed by determining conversion factors which will give equivalent results for processors offered by other contractors. Such a conversion task is difficult but must be accomplished and combined with consideration of schedule and reprogramming cost factors in the equipment selection process. These latter factors could ultimately lead to the constraint used in this analysis.

Only two assumptions are basic to the design process at the level described in this section. These are:

MSFN and ALDS data interfaces with the MCC-H will remain essentially unchanged.

Simulated MSFN and ALDS data inputs to the operational system will be indistinguishable from the corresponding LIVE mission inputs.

Description of Process

The MITRE design process is represented in Figure B.1-1. Its general structure consists of a series of sequential design steps whose ultimate product is the RTCC system cost associated with satisfying a particular set of requirements with a particular RTCC organization alternative. Progress toward the ultimate product is achieved in increments, each increment being associated with a particular step in the process. For this reason, each step in Figure B.1-1 is designated by the design result associated with that set; results for all steps other than Step 5 are considered preliminary. Making a complete "pass" through the design process requires that the designer pre-define the design case in which he is interested, first by selecting one of the eight RTCC organization alternatives, and second by assigning a value to each of the six (6) requirements variables. (Underlined in Figure B.1-1.)

Once the process is started, successful completion of each successive design step requires consideration both of the requirements variables associated with that step and of the tools, techniques and assumptions involved in translating values for requirements variables into quantitative design results. These two types of relevant data are designated in Figure B.1-1 as the "inputs" to each design step. Requirements variables and the general nature of their impact upon design results have been discussed previously. Inputs in the "tools, techniques and assumptions" category are discussed step-by-step below to the extent required to permit a general understanding of the design process. These are viewed as "bridging the gap" between requirements and design results.*

Step 2 - The "redundancy ratio" may be simply defined as the number of mission processing machines which may be supported by a single backup machine when the mission processing machines do not require dynamic standby backup. For example, it might be considered reasonable to provide one startup-type backup machine for every three mission processing machines. Such a ratio obviously influences the total number of machines involved in a given mission support complement.

Step 3 - Prior to Step 3, the number of mission support machines and the processing functions performed in each such machine have been defined. Outstanding is the task of identifying, given a processing load to be accommodated in the form of the vehicles requiring simultaneous support, the particular model of 360 Series machine capable of handling the load imposed on each computing element. First, an estimate is made for each element (or machine), using the RTCC loading estimators developed in Appendix A.3 of the % CPU time used assuming that element to be a 360/75. Secondly, ratios relating the computing speed of a 360/75 to that of other Series 360 machines may be employed to generate equivalent loads for the same set of real-time

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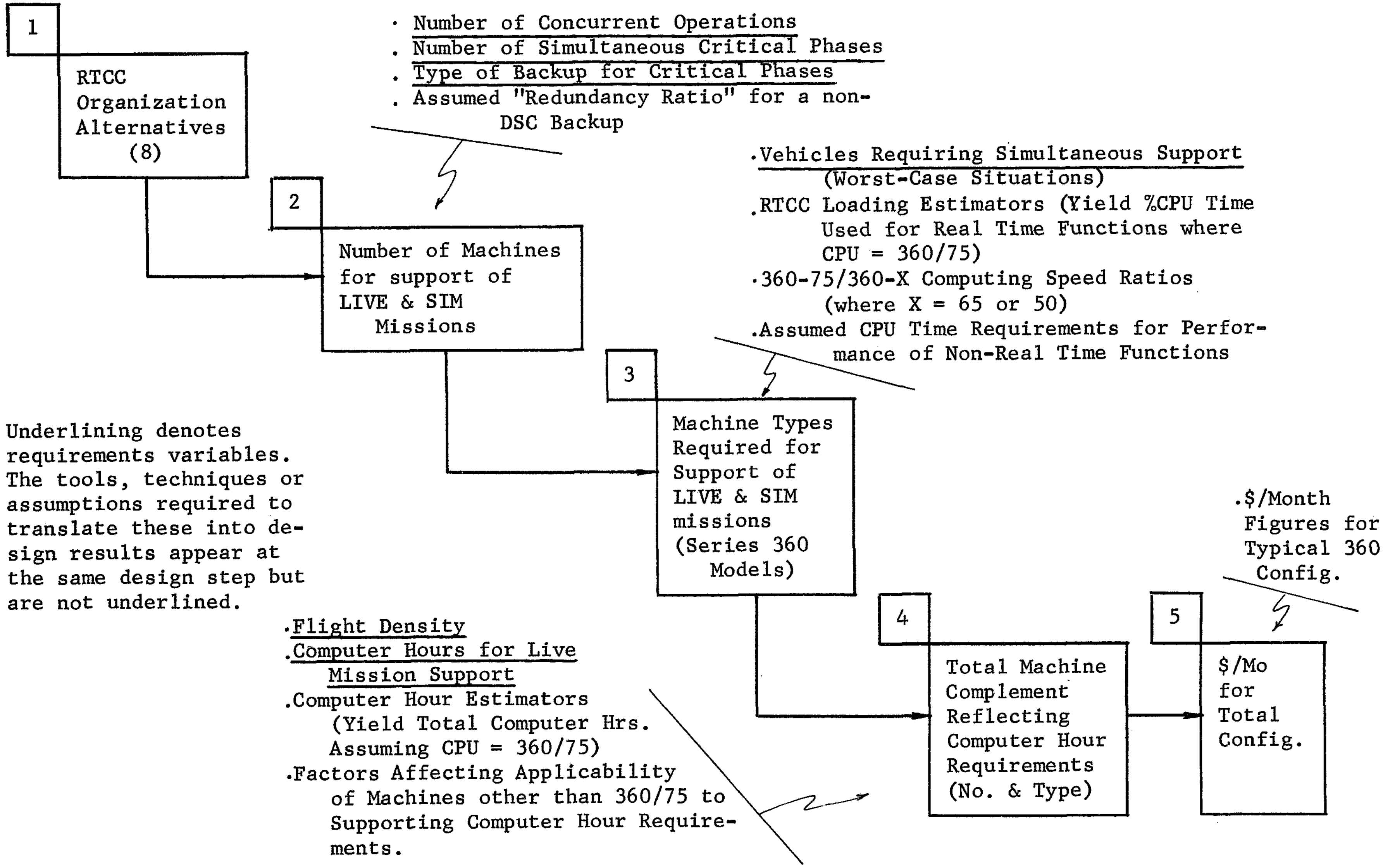
* A detailed and quantitative treatment of each such tool, technique and assumption is contained in Appendix B.4.



NOTE: Underlining denotes requirements variables. The tools, techniques or assumptions required to translate these into design results appear at the same design step but are not underlined.

FIGURE B.1-1

PROCESS FOR GENERATION OF RTCC DESIGN ALTERNATIVES AND ASSOCIATED COSTS functions. This second step supports a determination of which machine models other than a 360/75 are adequate to support at least the real-time processing load imposed on each of the elements. A final correlation between computing elements and machine models requires the application of an additional filter - an assumed minimum for the %CPU time (where CPU = 360/75) which must be available to support non-real-time processing functions* such as mission planning, command load generation, differential corrections, etc.

Step 4 - Using the Computer Hour Estimators developed in Appendix A.4, flight density may be translated into computer hour requirements for all activities considered preparatory to a mission or flight. To this may be added the computer hour requirements for support of actual missions by the particular type of RTCC organization being considered. The sum represents the total computer hours required assuming, due to the nature of the computer hour estimators employed, that all support is provided by 360/75 machines. A final determination of the total machine complement, allowing for a mix of different Series 360 machines, requires the consideration of quantitative factors which in effect convert hours on a 360/75 to equivalent hours on a 360/Model X where X = 50 or 65.

Step 5 - The input to this step simply reflects the decision that, at this relatively gross level of system design, adequate cost estimates may be made by using cost "building blocks" defined as the dollars per month to lease a representative configuration of 360 equipments based on one of the following central processing elements: Model 75, 65 or 50.

Note that Series 360 machines smaller than a 360/50 do not appear to warrant consideration.

Observe that the two most significant design tools - the estimators for both instantaneous loading and computer hour requirements - were developed in support of the review process. This commonality of tools between the review and design processes greatly encouraged the undertaking of a design effort.

Use of Process

Preceding paragraphs emphasize the manner of proceeding through the Figure B.1-1 design process on a step-by-step basis to complete a single "pass" through this process. Use of the process to develop the desired spectrum of cost vs. requirements for each of the eight (8) RTCC organization alternatives, however, requires many "passes" through the design process. As indicated above, each pass may be defined in terms of the combination of requirements being designed against (in the form of a set of requirements values, 1 value for each requirements variable) and the particular RTCC organization alternative of interest. An attack on the total objective, therefore, consists of defining all combinations of requirements considered to be of interest and then, for each such combination, making a pass through the design process for each of the eight RTCC alternatives.

*These have been described in Appendix A.3 as "event dependent trajectory processing functions."

More specifically, one might define all requirements combinations of interest (the total of 115 such combinations is developed in Appendix B.3) and then proceed in the following sequence.

Select a single requirements combination by assigning a specific value to each of the requirements variables.

Without modifying values for requirements variables, make eight passes through the design process (one for each functional allocation scheme).

Repeat for each different requirements combination.

Result: a total spectrum of cost vs. requirements for each of the eight (8) RTCC alternatives. This set of "raw" results is, of course, subject to further reduction or summarization as considered meaningful.

SUMMARY

A process has been developed and described which supports an investigation of the sensitivity of RTCC costs to requirements while at the same time considering alternative system organizations. Subsequent appendices support the application of this process as follows:

- Appendix B.2 provides, for M(P)-2A and ML-65-3, a derivation of values for the requirements variables previously identified. The resulting values are analogous to those derived in Appendix A.2 for the SR 500 models.

- Appendix B.3 compiles the values for all requirements variables in a form considered most useful for design purposes and specifically delineates all those combinations of requirements considered to be of design interest.

- Appendix B.4 presents detailed results and describes both the development and the detailed application of those tools, techniques, and assumptions critical to achieving these results. As such, this appendix represents a further expansion of a portion of the preceding material.

- Appendix B.5 discusses and summarizes the design results presented in Appendix B.4.

APPENDIX B.2

SUPPORTING SCHEDULE ANALYSIS

INTRODUCTION

Two manned spaceflight reference planning schedules for Apollo Applications, designated as ML-65-3 and M(P)-2A, are currently being used by NASA in considering requirements for the MCC-H in the post-Apollo era. The schedules are not official schedules but are representative of flights that are being considered for the post-Apollo time period and are therefore useful in determining the control requirements for the MCC-H. The statement of requirements for Augmentation II (SR 500) from the Flight Control Division (FCD) to the Flight Support Division (FSD) includes flight models which are related to the ML-65-3 schedule.

PURPOSE

This appendix is an analysis of the AAP reference planning flight schedules ML-65-3 and M(P)-2A. The analysis was conducted to obtain a better understanding of the material presented in SR 500 and to derive certain values for use in the review of the Augmentation II design approach.

The data contained herein will serve as an aid in determining the data processing requirements, for mission and non-mission periods, based on the density of the flight schedule and the number of vehicles and spacecraft involved in each flight configuration.

SCOPE

The results obtained in this analysis are based on assumptions which in turn are based on information gleaned from NASA generated documents, or generally agreed upon after many discussions with cognizant NASA operational personnel. The assumptions appear in the particular section of the analysis to which they apply.

The analysis is divided into two main parts. Part I contains data on flight and mission densities for each schedule, the average duration of each mission, an estimate of the computer time required to support live flights and the number of flights requiring RTCC computer program development during the maximum, minimum and average schedule month. Part II contains data on the number of vehicles and spacecraft requiring simultaneous trajectory computations, telemetry monitoring and the number of astronaut crews involved in each configuration. Similar requirements are then derived for the simulations necessary to support the live mission.

SCHEDULE DESCRIPTION

The main sections of the schedules, ML-65-3 and M(P)-2A, are shown in Figures B.2-1 and B.2-2 respectively. The sections shown, which include the peak loads and cover a 37 month period, should be sufficient to permit an accurate analysis.

The months on the schedule are numbered consecutively from one through 37. Each month (thirty days) is represented by one block. The types of flights involved in each schedule (i.e., 200 series and 500 series) are described in Part II of the analysis. The type of flight does not have a bearing on the analysis performed in Part I. The solid lines indicate the approximate duration of each flight. A flight which covers less than one-half of a block is assumed to be a ten day flight, one-half of a block indicates fifteen days, one block - thirty days, etc. Flights indicated by a diamond (♦) are unmanned target flights with an estimated total monitoring requirement time of 24 hours, after launch has been accomplished and the subsequent (rendezvous) flight is launched. The dotted lines, occurring for 45 days prior to each flight, signify the prelaunch periods in which vehicle/spacecraft checks, network checks and simulations are conducted.

DEFINITIONS

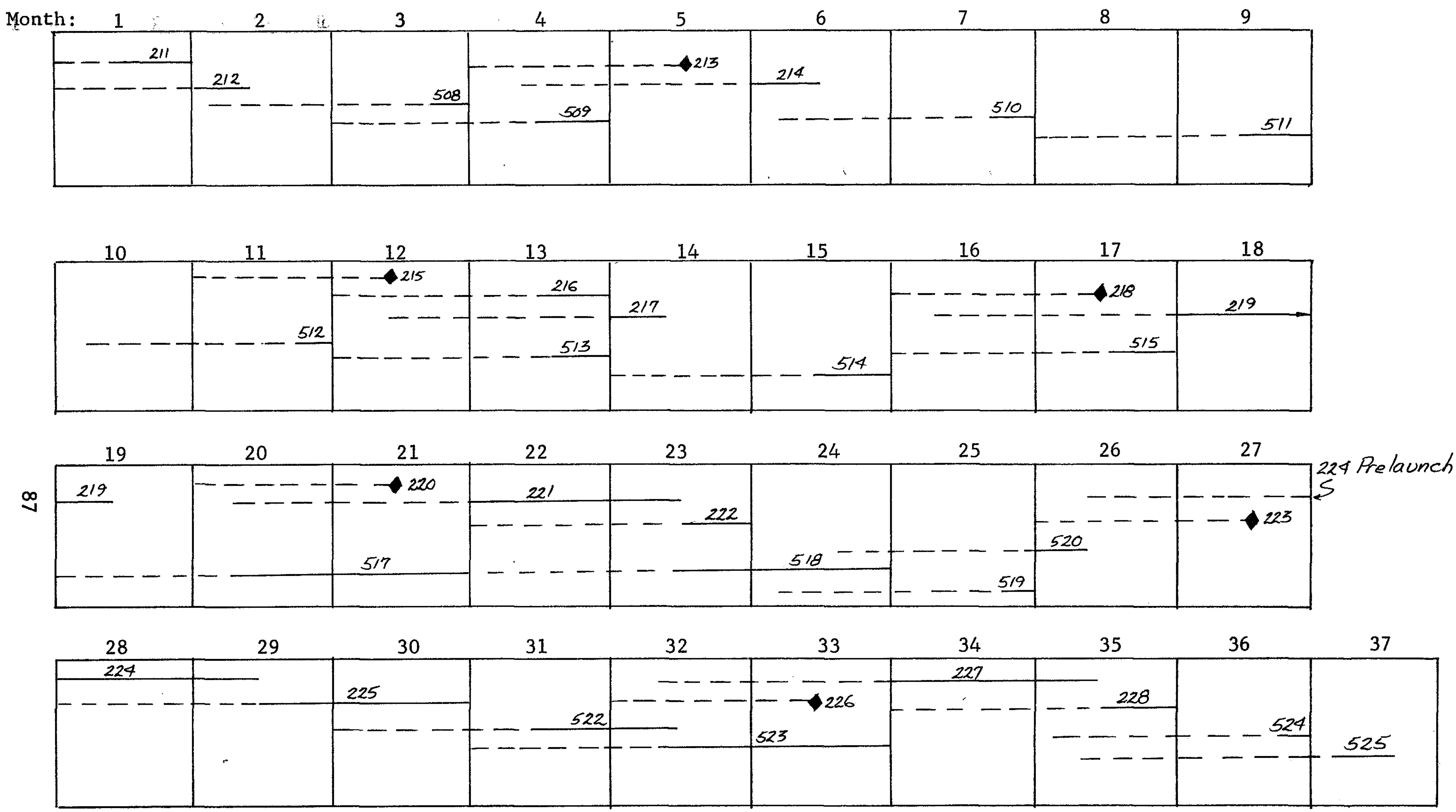
The following definitions will be used for the purpose of this analysis.

Flight - A flight is a single vehicle/spacecraft configuration, manned or unmanned, assigned a flight number on the schedule. In other words, the number of flights is equal to the number of launches.

Mission - A mission may consist of a single flight (such as a lunar mission where only one vehicle/spacecraft combination and crew is involved) or may be composed of a number of flights, launched separately, for the purpose of rendezvous, docking and interrelated experiments. For example, in M(P)-2A (Figure B.2-2), flights 507 and 213 constitute single-flight missions whereas 211/212 and 214/215/216 are multiple-flight missions.

The first section of Part I contains data on both flight and mission densities. All subsequent computations in Part I refer to individual flights since the total duration of a mission is the sum of the flight times of the individual subsequent flights making up the mission. For example, Flight 211 on ML-65-3 continues as part of Flight 212 until the termination of Flight 212 at which time mission 211/212 is concluded. The total mission time is the flight time of 211 plus the flight time of 212, or thirty days.

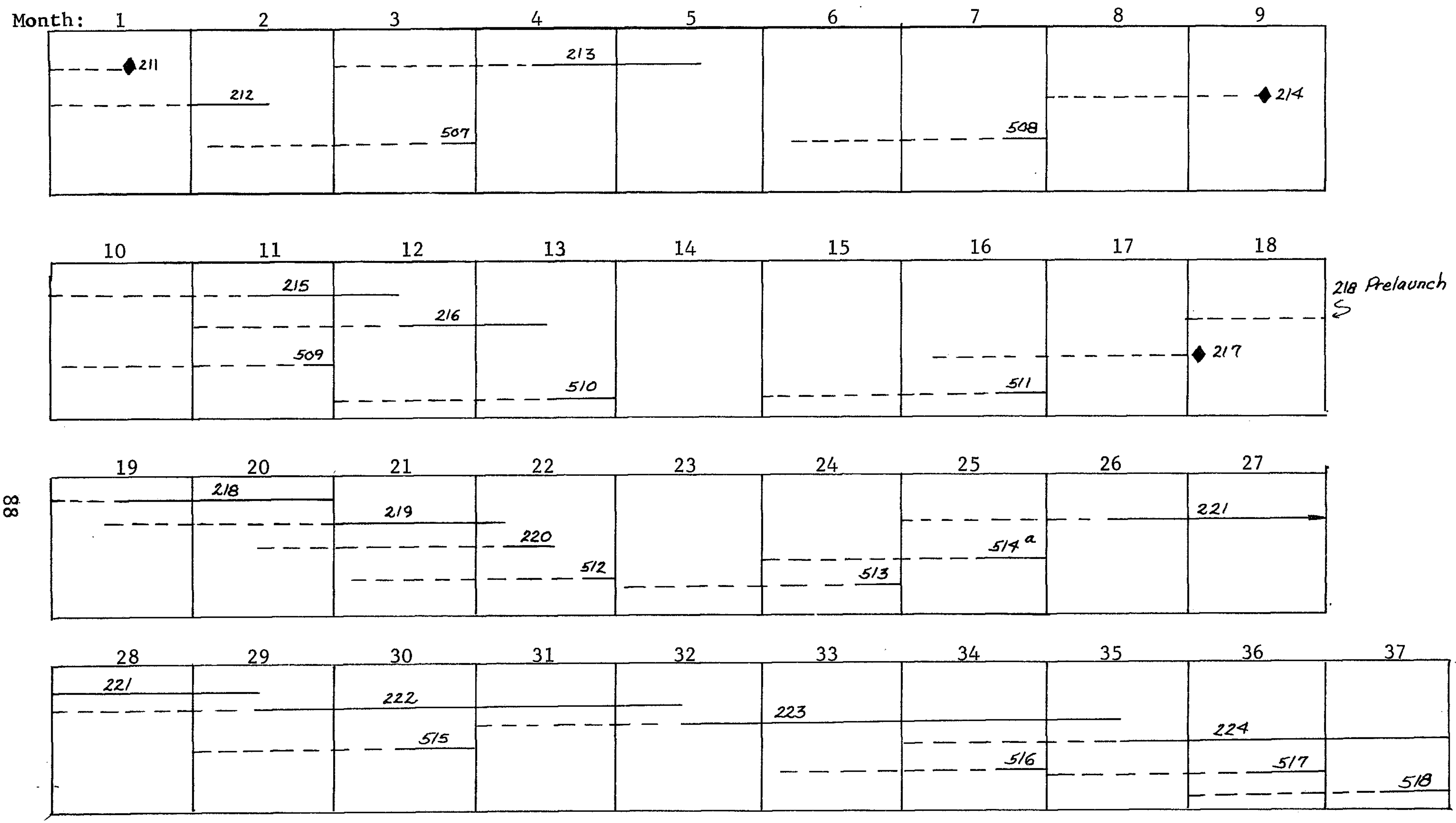
Vehicles vs. Spacecraft - For the purpose of this analysis, the word vehicle will apply to both boosters and spacecraft. ("Vehicle" usually refers to the rocket boosters designated to insert spacecraft into orbit or propel the spacecraft through space; while "spacecraft"



------PreLaunch
———Flight Time
◆ Target Launch

Figure B.2-1
SCHEDULE ML-65-3

<u>Multiple Flight Missions</u>
211/212
213/214
215/216/217
218/219
220/221/222
223/224/225
226/227/228



------PreLaunch
———Flight Time
◆ Target Launch
a514 is a supply ship for 221-224

Figure B.2-2
SCHEDULE M(P)-2A

Multiple Flight Missions
211/212
214/215/216
217/218/219/220
221/222/223/224

are manned or unmanned devices (CSM or LM) which are placed into orbit, or transport men and/or equipment through space).

PART I - FLIGHT ANALYSIS

Table B.2-I summarizes all of the Part I analysis. The table shows, for each schedule, the number of flights and missions, the RTCC computer hours required for live mission support under both mission and functional configurations and the number of flights requiring RTCC program development based on a six month development lead time. The following paragraphs in this part contain the computations used to determine the data in Table B.2-I.

Flight and Mission Densities

For the 37 months considered, the number of flights and missions counted are:

	FLIGHTS		MISSIONS		TOTALS	
	200 Series	500 Series	200 Series	500 Series	Flights	Missions
ML-65-3	19	16	7	16	35	23
M(P)-2A	14	12	5	11	26	16

A twelve month sliding window, imposed on each schedule, gives the maximum number of flights in any twelve month period. The results are:

ML-65-3 maximum flights/year = 13
M(P)-2A maximum flights/year = 10

The maximum flights/month for each schedule is:

ML-65-3 13/12 = 1.08 flights/month
M(P)-2A 10/12 = .83 flights/month

The average number of flights per year and per month for the 37 month schedules is defined as:

$$\text{ML-65-3} \quad \frac{35 \text{ flights}}{37 \text{ months}} \times 12 \text{ months} = 11.4 \text{ flts/yr or } .95 \text{ flts/mo.}$$

$$\text{M(P)-2A} \quad \frac{26 \text{ flights}}{37 \text{ months}} \times 12 \text{ months} = 8.4 \text{ flts/yr or } .70 \text{ flts/mo.}$$

The average number of missions per year and per month is:

ML-65-3 23/37 x 12 = 7.46 miss/yr. = .62 miss/mo.
M(P)-2A 16/37 x 12 = 5.19 miss/yr. = .43 miss/mo.

SCHEDULE	FLIGHT AND MISSION DENSITIES							
	FLIGHTS					MISSIONS		
	TOTAL	MAx/Yr[a]	Max/Mo	Avg/Yr[a]	Avg/Mo	TOTAL	Avg/Yr[a]	Avg/Mo
ML-65-3	35	13	1.08 n	11.4	.95	23	7.5	.62
M(P)-2A	26	10	.83	8.4	.70	16	5.2	.43

SCHEDULE	RTCC COMPUTER HOURS FOR LIVE MISSION SUPPORT			
	MISSION CONFIGURATION[b]		FUNCTIONAL CONFIGURATION[e]	
	Total Flight Hours[c]	Total RTCC Hours/Mo.[d]	Total Flight Hours[f]	Total RTCC Hours/Mo.[d]
ML-65-3	15,408/37 mo. 416/mo.	450	13,608/37 mo. 368/mo.	402
M(P)-2A	17,688/37 mo. 478/mo.	503	16,128/37 mo. 436/mo.	461

FLIGHTS REQUIRING PROGRAM DEVELOPMENT		
Max	Min	Average
7	4	5.7
5	2	4.2

TABLE B.2-I

SUMMARY OF PART I ANALYSIS

[a] year refers to a 12 month period - not a calendar year
[b] single computer per mission
[c] sum of all flight time in 37 month period from liftoff to recovery
[d] total flight hours per month plus dynamic standby, countdown and pad support time of 36 hours/flight
[e] multiple computers where each machine is dedicated to processing one type of data for all missions
[f] sum of flight time in 37 month period where overlapping flights are counted as one value

RTCC Computer Hours for Live Mission Support

The RTCC computer hours for live mission support are calculated for an average month for both mission and functional RTCC configurations. The requirements include three major items. The first is the actual mission duration from liftoff to recovery and is found by adding the estimated duration of the flights, as interpreted from the schedule description on page 86, and dividing by the 37 months being considered. The second item considered is the dynamic standby computer (DSC) time requirement. An average time of twelve hours per flight for the DSC is assumed to be adequate to support all critical phases. Thirdly, 24 hours of RTCC computer time is added to each flight representing pad support, countdown, etc.

Mission Configuration

In a mission configuration, one RTCC computer handles all the data processing required for a single mission. The total live mission time for each schedule is the sum of all flight times and is found to be:

ML-65-3 15,408 hrs/37 mo. or 416 hrs/mo.
M(P)-2A 17,688 hrs/37 mo. or 478 hrs/mo.

This represents the average time required per month without DSC or pad support time.

If a DSC is assigned on an average of twelve hours per flight, and 24 hours per flight is allowed for pad support, countdown, etc., the average time per month becomes:

ML-65-3 (36 hrs x 35 flts)/37 mo. + 416 hrs = 450 hrs/mo.
M(P)-2A (36 hrs x 26 flts)/37 mo. + 478 hrs = 503 hrs/mo.

Functional Configuration

In various functional configurations, separate RTCC computers are assigned to process telemetry, trajectory and display data. Each computer is common to all missions in progress, thereby processing the telemetry data for all missions, the trajectory data for all missions, etc. In this configuration the overlapping flight time of two flights on the schedules (e.g., a 200 and 500 series flight) is not added separately, as in the mission configuration, but is added as one value.

The total live mission time for each schedule in the functional configuration is:

ML-65-3 13,608 hrs/37 mos. or 368 hrs/mo.
M(P)-2A 16,128 hrs/37 mos. or 436 hrs/mo.

without DSC or pad support time.

The DSC and pad support time is then added, as in the mission configuration, giving:

ML-65-3 34 hrs/mo. + 368 hrs/mo. = 402 hrs/mo.
M(P)-2A 25 hrs/mo. + 436 hrs/mo. = 461 hrs/mo.

Flights Requiring Program Development

The number of flights requiring RTCC program development in any given month may also be determined from the schedules. The analysis of Gemini and Apollo developments schedules indicated that an average of six months is allocated to develop the programs for a flight. Using this information, a six month sliding window on the schedules indicates that the maximum and minimum number of flights requiring program development in a single month are:

ML-65-3	7 maximum	4 minimum
M(P)-2A	5 maximum	2 minimum

The average number of flights requiring development in a single year is equal to the average number of flights per year, or 11.4 for ML-65-3 and 8.4 for M(P)-2A. The average number of flights requiring program development in a single month is equal to one-half the average number of flights.

Average Programs in Development	
ML-65-3	5.7 programs
M(P)-2A	4.2 programs

Simulation Time

The hours required for the development, checkout and implementation of simulation programs and exercises is discussed in Appendix A.4. These hours will be added to the mission times together with other requirements to determine total RTCC hours required.

PART II - VEHICLE LOADING ANALYSIS

Description of Flights Types and Vehicles

The flights specified in ML-65-3 and M(P)-2A are either the 200 series (earth orbit) or 500 series (lunar missions and synchronous earth orbit). The 500 series employs the S-IC, S-II and S-IVB boosters as launch vehicles and the 200 series flights use the S-I and S-IVB boosters. The spacecraft for the 500 series flight are CSM and the LM. Both will be part of every 500 series launch configuration.* The LM may be

*The LM may be replaced by other equipment for a synchronous earth or lunar orbit but because of the indefinite specifications such payloads are assumed to be equal to a LM.

configured as a LM taxi or a LM shelter. The LM shelter will be transported to the moon in the same manner as a LM taxi (by a manned CSM) but will be automatically soft landed for future occupancy by a crew which will arrive on a subsequent flight via a LM taxi. The spacecraft for the earth orbit flights is either a CSM or a LM laboratory. In addition, an S-IVB "spent stage" may be used as an orbiting laboratory. The 200 series boosters cannot orbit both the CSM and LM laboratory in the same flight. The LM laboratory will be launched as an unmanned flight and subsequent flight(s) will orbit the CSM or CSM/S-IVB spent stage. Rendezvous and docking will then be accomplished in a number of vehicle configurations. Experiment modules (EM) will be used on many flights. An EM may consist of an Apollo telescope mount (ATM), a mapping and survey system (M&SS), an Apollo lunar surface equipment package (ALSEP) or other EM's not yet defined.

Live Mission Vehicle Loads

Flight Matrix

Figure B.2-3 is a matrix showing all the single-flight vehicle combinations for all flight phases in both the 200 series and 500 series flights.* The construction of the matrix is based on the following assumptions which suggest maximum load conditions.

(a) An EM is assigned to each vehicle combination except in the S-IVB spent stage/CSM combination where S-IVB constitutes an EM.

(b) All 500 series flights are depicted as lunar flights including a LM (rather than lunar orbit or synchronous earth orbit which may not require the LM, per se).

(c) The LM and EM are included in all applicable launch cases even though they may be passive in a realistic situation.

Maximum Vehicle Combinations in Live Missions

Since Figure B.2-3 depicts "all possible" vehicle configurations for a 200 or 500 series flight it is possible to determine the maximum vehicle loads, telemetry and trajectory requirements and number of crews imposed on the MCC-H for any combination of these flights. Having found the maximum figures it is then possible to determine if and where the maximum loads might occur in ML-65-3 and M(P)-2A. Table B.2-II contains the maximum telemetry, trajectory and crew requirements imposed by the maximum vehicle loads found in the matrix in Figure B.2-3 and in the schedules ML-65-3 and M(P)-2A. The following paragraphs describe the processes involved in arriving at these totals.

*In the discussion following, reference to a particular series and phase of a flight on the matrix is made by use of the latter A or B (indicating the series) and the numbers 1 - 8 (indicating the flight phase), e.g., A1 is a 500 series launch, B7 is a 200 series reentry.

FLIGHT PHASE / SERIES	PRELAUNCH (1)	LAUNCH (2)	EARTH ORBIT (3)	TRANS-LUNAR[a] (4)	LUNAR VICINITY (5)	TRANS-EARTH (6)	REENTRY (7)	LUNAR RESIDUAL (8)
500 SERIES (A)	S-IC S-II S-IVB CSM LM EM	S-IC S-II S-IVB CSM LM EM	S-IVB CSM LM EM	CSM LM EM	CSM LM EM	CSM EM	CM	EM or LM[b]
200 SERIES (B)	S-I S-IVB[c] CSM(orLM) EM	S-I S-IVB[c] CSM(orLM) EM	[e] S-IVB[d] CSM - - - - EM CSM - - - - EM LM	-	-	-	CM	-

Figure B.2-3
POSSIBLE VEHICLES TO BE TRACKED OR MONITORED
(BY FLIGHT PHASE)

[a]also synchronous earth orbit phase
[b]monitor only one at a time
[c]workshop and/or booster
[d]workshop (spent-stage)
[e]three combinations of 2 vehicles each, resulting from three separate launches - any or all may be in orbit at one time.

PHASE / SOURCE	LAUNCH								NON-LAUNCH							
	Single Series[b]				Combined Series				Single Series[b]				Combined Series			
	Veh	Tlm	Traj	Crews	Veh	Tlm	Traj	Crews	Veh	Tlm	Traj	Crews	Veh	Tlm	Traj	Crews
MATRIX[a]	8	8	3[c]	2	11	11	3[c]	2	6	6	2[d]	2	10	10	4[e]	3
ML-65-3	8	8	3[c]	2	11	11	3[c]	2	6	6	2[d]	2	10	10	4[e]	3
M(P)-2A	8	8	3[c]	2	11	11	3[c]	2	6	6	2[d]	2	8[f]	8[f]	4[e]	2

Table B.2-II
MAXIMUM TELEMETRY, TRAJECTORY, CREWS
BASED ON MATRIX AND SCHEDULE VEHICLE LOADS

[a] maximum loads based on ground rules
[b] maximum for single series occurs in 200 series both launch and non-launch phases
[c] one trajectory for launch vehicle plus two for undocked orbiting vehicles
[d] maximum of two trajectories for undocked vehicles
[e] two for lunar descent or ascent and two for undocked vehicles in earth orbit
[f] only case where schedules indicate less load than that suggested by matrix

Ground Rules

The number of flights which can be flown or controlled at one time is restricted by vehicle delivery, launch support equipment and control facilities. Based on these constraints, published mission profiles and discussions with NASA personnel, the following ground rules have been applied when determining the maximum vehicle loads:

(1) Pad support will not be required with maximum vehicle load support situations.

(2) Control of 500 series flights and 200 series flights will occur on different floors of the MOW.

(3) Launches will not occur under the following conditions:

a. A 500 series launch while a manned 500 series mission is in progress.
b. Within 24 hours of a previous launch.
c. When two CSM are in earth orbit effecting a crew change for reentry.
d. When a CM is in the reentry phase.

(4) Lunar injection (the burnout and jettison of the S-IVB) will be accomplished within twelve hours of launch.

(5) One EM (orbiting or on lunar surface) or unmanned lunar vehicle will be included in all cases even though limited or no monitoring may be required at certain times (A8 of the matrix).

(6) The maximum number of vehicles in earth orbit on a single mission will be six (6) no matter how many flights are scheduled for the mission. (This provides for all vehicles in B3 of the matrix.)

Loads During Launch Phase

Maximum in Single Series - the maximum vehicle load during the launch of a single series (200 or 500) is a 200 series launch (B2) plus four orbiting vehicles (2/3 B3) = 8 vehicles.

Maximum in Combined Series - the maximum vehicle load in combined 200/500 flights during a launch is a 500 series launch (A2) plus four vehicles in earth orbit (2/3 B3) plus the residual EM (A8) = 11 vehicles. Ground rule 3-C does not allow the inclusion of all vehicles in B3; i.e., two crews on station during a launch.

Loads During Non-Launch Phase

Maximum in Single Series - the maximum vehicle load for a single series during a non-launch period is six orbiting earth vehicles (B3).

Maximum in Combined Series - the maximum multiple vehicle load in a combined 200/500 series is six earth orbit vehicles (B3) plus three translunar or lunar vicinity vehicles (A4 or A5) plus (A8) = 10.

Comparison of Matrix Loads to Schedules

The single-series maximum loads which occur in 200 series missions may be found in ML-65-3 during the launch and flights of 217, 222, 225 and 228. They may be found in M(P)-2A during the launch and flights of 215, 219, 220, 223 and 224.

In attempting to match the matrix maximum combined-series launch loads (11 vehicles) to the schedules it is found that the maximum launch load occurs twice in ML-65-3 (during the launch of 510, 515, 516, 517 or 518 if the two previous 200 series flights are in orbit in each case).

The maximum combined-series non-launch condition (10 vehicles) appears in ML-65-3 once if flights 220/221/222 are in earth orbit and 518 is in the translunar or transearth phase. (Flight 222 is launched after 518 in order to obtain this condition.)

The maximum non-launch condition of ten vehicles is not present in M(P)-2A. What is the maximum non-launch load in M(P)-2A? The next possible maximum combined-series non-launch condition, as per the matrix, is nine vehicles which includes a 500 series flight in the transearth phase (A7), plus six orbiting earth vehicles (B3), and the residual EM (A8); but this condition cannot be found on the M(P)-2A schedule either. The next worst load is eight vehicles, four in earth orbit (2/3 B3) plus three in translunar or lunar vicinity phase (A4 or A5) plus the EM (A8). This load is found in M(P)-2A during the flights of 510, 515, 516, 517 and 518 and constitutes the maximum combined-series non-launch vehicle load for M(P)-2A.

Simulation Vehicle Loads

Simulated Flight Matrix

The matrix in Figure B.2-4 is a vehicle load, by phase, for simulated vehicles, similar to the vehicle loads described for live flights shown in Figure B.2-3. The vehicles loads in Figure B.2-4 differ somewhat from the live loads because of simulation constraints and training procedures. The maximum simulated vehicle loads are derived from the matrix as described in the following paragraphs.

Ground Rules

Certain constraints which result from the live flight problems, have been imposed on the implementation of simulated missions and the resulting vehicle loads. The following ground rules have been applied when determining the maximum simulated vehicle loads.

(1) No simulations will be conducted during an actual launch.

(2) Only one simulated launch may be conducted at one time in the MOW.

(3) Simulations on the lunar floor (500 series) will not be conducted when a manned lunar mission is in progress.

(4) Simulations on the earth orbit floor (200 series) may be conducted when no more than two earth orbit flights are active and when neither of these flights is in reentry phase.

(5) A simulation on one floor may be conducted concurrent with any non-launch live operation (except reentry) on the other floor.

The above ground rules, based on SR 500 simulation requirements and live mission constraints, result in the following conditions under which simulations may be conducted:

CONDITION	LIVE MISSION(S) IN PROGRESS	SIMULATION(S) PERMITTED	
		LUNAR FLOOR	EARTH ORBIT FLOOR
I	Earth Orbit of 3 flights[b]	Launch, Lunar Flight, Reentry	NONE
II	Lunar Flight	NONE	Launch, Earth Orbit, Reentry
III	Lunar Flight, plus Earth Orbit of 3 flights[b]	NONE	Launch, Earth Orbit, Reentry
IV	NONE	Launch[a], Lunar Flight, Reentry	Launch[a], Earth Orbit, Reentry
V	Earth Orbit of 3 Flights	Launch[a], Lunar Flight, Reentry	Launch[a], Earth Orbit, Reentry

TABLE B.2-III

POSSIBLE SIMULATED MISSIONS

[a]Only one launch at a time
[b]If not in reentry phase

FLIGHT PHASE / SERIES	LAUNCH (1)	EARTH ORBIT (2)	TRANS-LUNAR (3)	LUNAR VICINITY (4)	TRANS-EARTH (5)	REENTRY (6)
500 SERIES (C)	S-I [a] S-II S-IVB CSM	-	CSM LM EM	CSM LM EM	CM EM	CM
200 SERIES (D)	S-I [b] S-IVB CSM (or LM)	[c] CSM EM - - - - LM EM	-	-	-	CM

Figure B.2-4
POSSIBLE SIMULATED VEHICLES TO BE MONITORED
(BY FLIGHT PHASE)

[a]LM and EM passive
[b]EM passive
[c]two combinations of two vehicles each - either or both may be in orbit at one time

Maximum Simulated Vehicle Loads

Using the above conditions for simulated missions we obtain the following maximum simulated vehicle loads from Figure B.2-4.

CONDITION I a. 500 launch (C1) = 4 — Total 4 vehicles
b. 500 flight (C3 or C4) = 3 — Total 3 vehicles

II a. 200 launch (D1) = 3 — Total 3 vehicles
b. 200 orbit (D2) = 4 — Total 4 vehicles

III Same as Condition II

IV a. 500 launch (C1) = 4 + 200 Orbit (D2) = 4
Total 8 vehicles
b. 500 flight (C3 or C4) = 3 + 200 Launch (D1) = 3
Total 6 vehicles
c. 500 flight (C2 or C4) = 3 + 200 Orbit (D2) = 4
Total 7 vehicles

V Same as Condition IV

Maximum Live Plus Simulated Vehicle Loads

As shown in the section on live vehicle loads (Table B.2-II) the maximum vehicle load for the matrix and schedules was eleven vehicles and four trajectories. The addition of the simulated vehicle load to one of the live loads may, however, impose a greater load on the system than if the live load is taken separately.

Using Table B.2-III, which indicates the conditions under which simulated mission may be conducted, the data obtained in the analysis of the live missions, we can construct Table B.2-IV which will determine the maximum vehicles and associated telemetry and trajectory requirements imposed by the live and simulated combinations.

CONDITION	LIVE VEHICLES(TLM)[a]	LIVE TRAJ	SIM VEHICLES(TLM)[a]	SIM TRAJ	TOTAL V(TLM)[a]	TOTAL TRAJ
I	7	2	4	1	11	3
II	4	2	4	2	8	4
III	8	3	4	2	12	5
IV	0	0	8[b]	3	8	3
V	5	2	8[b]	3	13	5

TABLE B.2-IV

MAXIMUM VEHICLES INCLUDING LIVE AND SIMULATED FLIGHTS

[a]The number of vehicles is equal to the number of telemetry sources.
[b]Assumes both floors conducting a simulation

Conditions III and V impose greater loads on the system than the maximum live load of eleven vehicles and four trajectories shown in Table B.2-II. Based on the ground rules set forth, the greatest possible load on the system is Condition V, thirteen vehicles and five trajectories, which indicates two simulations in progress at one time. The maximum case for one simulation is found in Condition I, which shows eleven vehicles and three trajectories.

Verification of Maximum Load in ML-65-3 and M(P)-2A

It is necessary to determine if the maximum load noted above in Condition V (thirteen vehicles) might occur in ML-65-3 and M(P)-2A. A study of each schedule indicates that it probably would not occur as the schedules are shown in Figure B.2-1 and B.2-2, but could become a reality with certain schedule slippages. The maximum simulation-plus-live condition found in the schedules is Condition III, twelve vehicles. It is present in ML-65-3 when flight 217 is in a simulated rendezvous and flights 215/216 are in flight and in M(P)-2A when flight 223 is in a simulated rendezvous while flights 221/222 and 515 are in flight.

APPENDIX B.3

DETAILED CONSIDERATION OF THE POST-APOLLO REQUIREMENTS SPECTRUM

INTRODUCTION

The Appendix B.1 treatment of operational requirements included the introduction of the "requirements variable" concept, the identification of such variables for purposes of the MITRE design effort, and a discussion of their role in generating design results by employing the Figure B.1-1 design process. In particular, the need to define all possible combinations of requirements was identified, noting that a single combination of requirements consists of a unique set of values for the six requirements variables. Viewing this appendix as an extension of Appendix B.1's treatment of requirements, its purpose is to:

> Compile, in a form appropriate for support of the Figure B.1-1 design process, the range of possible values for each of the selected requirements variables. Compilation rather than formulation is involved because all such values have been stated and/or derived in other appendix material.
>
> Specify all combinations of requirements which are of design interest. These combinations constitute the spectrum of requirements for which design results are to be developed.

Referring to Figure B.1-1, requirements variables appear as inputs to three successive steps in the design process - steps 2, 3 and 4. Requirements and combinations thereof are discussed below first on a design-step by design-step basis. This appendix is then concluded by considering the interaction between these requirements and the resulting total number of requirements combinations.

REQUIREMENTS ASSOCIATED WITH EACH DESIGN STEP

Consult Figure B.1-1 and the associated text for any clarification of the design steps referred to below.

<u>Requirements Impacting Upon the Number of Mission Support Machines</u>
(Reference Step 2 of design process)

Three requirements variables affect the number of required mission support machines. First of all, the twelve possible combinations of the following values for the three variables are of design interest:

# of concurrent operations - 2, 3, 4	(3 values)
# of simultaneous critical phases - 1 or 2	(2 values)
Type of backup for critical phases - DSC or Startup/Startover	(2 values)

When considering the interaction between these variables, however, one discovers that additional combinations of values for these requirements warrant consideration as a special case. More than two concurrent operations implies simulation or pad support activity which may be discontinued if additional computers are required to support a critical phase contingency. A value of "0" for the number of simultaneous critical phases, therefore, may be legitimately combined with values of three or four for the number of concurrent operations. Consideration of these additional combinations allows the designer to "take advantage" of the ability to schedule prelaunch activities and "planned" critical phases such that the maximum number of concurrent operations is never coincident with the maximum number of simultaneous critical phases. "Taking advantage" in this case amounts to requiring fewer machines for direct mission support than would be required if the maximum values for the two requirements variables were allowed to be coincident. Without detailed discussion, allow it to be stated that these "special case" combinations warrant design consideration only for system organization alternatives involving mission-oriented machines (pure mission or mission/display hybrid alternatives) and then only when dynamic standby backup for critical phases is assumed; no other cases offer the same potential machine savings. In lieu of such savings, these "special" requirements combinations are not of interest.

Additional consideration of the design significance of the number of simultaneous critical phases yields the conclusion that the <u>type</u> of critical phase - launch versus non-launch - as well as the number is important in the Launch/Function Hybrid case. Because launch is treated as a special case by this organizational scheme, the number of required machines (at Step 2) to support a given number of simultaneous critical phases is affected by whether or not a launch is included. It may be shown, in fact, that a greater number of machines is always required when a launch is assumed. To generate worst-case results, therefore, all design results for the Launch/Function Hybrid case are generated assuming a single launch. Design results based on this assumption show, furthermore that any Launch/Function configuration which supports one critical phase where that critical phase is a launch will also support two critical phases if neither is a launch. This observation is important to the interpretation of design results for the Launch/Function case.

Based on the above, Table B.3-I presents all combinations of the three requirements which are to be "designed against." For each RTCC organization alternative, design results may be developed for each of these fourteen combinations.

<u>Requirements Affecting Machine Loading and Selection of Machine Types</u>
(Reference Step 3 of design process)

The "Vehicles requiring simultaneous support" is the only requirements variable which affects machine loading as per Figure B.1-1 design process. Values for this variable are derivative from the mission models and reference planning schedules, worst-case situations being of interest in support of estimating maximum CPU time usage. To permit "% CPU Time Used" sizing of RTCC configurations which both do and do not support launch as a special case, vehicle loads with and without launch have

TABLE B.3-I

COMBINATIONS OF REQUIREMENTS AFFECTING THE NUMBER OF DIRECT SUPPORT MACHINES

COMBINATIONS	TYPE OF CRIT. PHASE BACKUP	NUMBER OF SIMULTANEOUS CRIT. PHASES	TYPE OF CRITICAL PHASE[a]	NUMBER OF CONCURRENT OPERATIONS
1	Dynamic	2	1 Launch	4
2	Standby			3
3				2
4		1	1 Launch[c]	4
5				3
6				2
7[b]		0	N. A.	4
8[b]				3
9	Startup/	2	1 Launch	4
10	Startover			3
11				2
12		1	1 Launch[c]	4
13				3
14				2

NOTES:

[a]Significant only when considering Launch/Function Hybrid alternatives.

[b]These combinations are of design interest only when considering the pure Mission of the Mission/Function alternative.

[c]A Launch/Function Hybrid configuration capable of supporting 1 launch can also support 2 critical phases if neither of these is a launch.

been developed for each model and schedule. To permit investigation of sizing sensitivity to the number of concurrent operations, vehicle loads with and without simulations have been developed. Table B.3-II, parts A through D, presents the resulting derivations in a form convenient for loading estimation. As an example, reference Table B.3-IIA for requirements derivative from the SR 500 Prime Model. The left column entries define a number of multiple-mission cases based on the number of concurrent operations and the with and without launch distinction noted previously. Multiple-mission cases are of interest when sizing any configuration involving other than standalone elements. In addition, a single mission case is presented in support of estimating loading for standalone elements. For each case, the five "vehicles to be supported" columns specifically identify the vehicle support requirements. (See the key associated with Table B.3-II for a description of the conventions employed.) The first four of these present a breakdown of the total number of vehicles to be supported into categories defined primarily by mission phase and/or mission type with lunar residuals treated as a special case. The fifth column presents a case summary of both telemetry and trajectory support requirements.

Tables B.3-IIA and B.3-IIB are based on Appendix A.2 material concerning the SR 500 models. Tables B.3-IIC and B.3-IID are based on Appendix B.2 material concerning the reference planning schedules. See these other appendices for a discussion of the analyses and assumptions which led to the tabulated results. Subsequent paragraphs discuss the combining of vehicle support cases with the values for flight density and the number of direct support computer hours derived for each model and schedule.

Requirements Related to Computer Hours
(Reference Step 4 of design process)

Two requirements variables are associated with the totality of computer hour demands: flight density and the number of computer hours for support of live missions. Values for each variable have been derived from each of the two models and two reference planning schedules. Results are presented in Table B.3-III. In general, information pertaining to the SR 500 models has been compiled from Appendix A.2 while information pertaining to the reference planning schedules has been compiled from Appendix B.2.

As discussed in Appendix A.2, flight density for the SR 500 models is given as a constant for the duration of the post-Apollo program. For the schedules, however, Table B.3-III distinguishes between average density (computed over the duration of the schedules) and peak density (the greatest number of flights in any single twelve month period). Although the derivation of these values is explained in Appendix B.2, some discussion is warranted concerning why such a distinction is of design interest. Simply stated, it may be assumed that the computer hour scheduling process will evenly distribute computer hour demands in a manner which eliminates short-term peaks. On the other hand, peaks of a relatively long duration may not lend themselves to such "smoothing." In particular, a system which is designed to support the average computer hour requirements for the duration of the post-Apollo program will be able to "work off" short-term peaks by scheduling to adjacent low

TABLE B.3-II

WORST-CASE SIMULTANEOUS VEHICLE SUPPORT REQUIREMENTS

Different formulations for the worst-case vehicle support situations are presented in this set of tables for each of four requirements sources as follows:

- SR 500 Prime Model - See Table B.3-IIA
- SR 500 Interim Model 3 - See Table B.3-IIB
- M(P)-2A - See Table B.3-IIC
- ML-65-3 - See Table B.3-IID

The following key applies:

A B C	Vehicles A, B, and C are docked or combined and, therefore, are considered as a single vehicle from a tracking viewpoint.
$\boxed{X}$ $\boxed{Y}$	Vehicle combination "X" is rendezvousing with vehicle combination "Y".
LCH	Launch
H. S.	High-Speed
L. S.	Low-Speed
TLM	Telemetry
TRJ	Trajectory

TABLE B.3-IIA

SIMULTANEOUS VEHICLE SUPPORT REQUIREMENTS
Worst-Case Situations from SR 500 Prime Model

CASES OF INTEREST	VEHICLES TO BE SUPPORTED				
	In Launch	Inflight E.O. Vehicles	Inflight Lunar Vehicles	Lunar Surface Vehicles	Total No. of Vehicles
<u>For Live Missions Only (up to two)</u>					
All missions; a launch included	SI SII SIVB LM CSM EM 500	CSM LM EM EM CSM EM	–	EM	TLM, 13 TRJ, 3 1 LCH 1 H.S. 1 L.S.
All missions; no launch included	–	CSM LM EM EM CSM EM	CSM EM LM LUNAR DESCENT	EM	TLM, 10 TRJ, 4 2 H.S. 2 L.S.
Any single mission (may be multi-flight)	SI SIVB CSM EM 200	CSM LM EM EM	–	–	TLM, 8 TRJ, 2 1 LCH 1 L.S.
<u>For Live + 1 SIM Mission (Up to three)</u>					
A simulated launch included	SI SIVB CSM SIM 200	CSM LM EM EM LIVE	CSM LM EM LIVE	EM LIVE	TLM, 11 TRJ, 3 1 LCH 2 H.S.
No simulated launch included	–	LM CSM EM EM LIVE LM EM CSM EM SIM	CSM EM LIVE, LUNAR DESCENT LM	EM LIVE	TLM, 12 TRJ, 5 3 H.S. 2 L.S.
<u>For Live + 2 SIM Missions (Up to four)</u>					
A simulated launch included	SI SII SIVB CSM SIM 500	LM CSM EM EM LIVE LM EM CSM EM SIM	–	EM LIVE	TLM, 13 TRJ, 4 1 LCH 1 H.S. 2 L.S.
No simulated launch included		LM CSM EM EM LIVE LM EM CSM EM SIM	LM CSM EM LIVE	EM LIVE	TLM, 12 TRJ, 4 2 H.S. 2 L.S.

TABLE B.3-IIB

SIMULTANEOUS VEHICLE SUPPORT REQUIREMENTS
Worst-Case Situations from SR 500 Interim Model 3

CASES OF INTEREST	VEHICLES TO BE SUPPORTED: In Launch	Inflight E. O. Vehicles	Inflight Lunar Vehicles	Lunar Surface Vehicles	Total No. of Vehicles
For Live Missions Only (Up to two)					
All missions; a launch included	SI SIVB CSM EM 200	CSM LM EM EM		EM	TLM, 9 TRJ, 2 (1LCH, 1H.S.)
All missions; no launch included		CSM LM EM EM; CSM EM		EM	TLM, 7 TRJ, 2 (1H.S, 1L.S.)
Any single mission (may be multi-flight)	SI SIVB CSM EM 200	CSM LM EM EM	NOTE: Same as for Prime Model		TLM, 8 TRJ, 2 (1L.S, 1LCH)
For Live + 1 SIM Mission (Up to three)					
A simulated launch included	SI SIVB CSM SIM 200	CSM LM EM EM LIVE		EM_{LIVE}	TLM, 8 TRJ, 2 (1LCH, 1H.S.)
No simulated launch included		CSM LM EM EM LIVE; CSM EM; LM EM SIM		EM_{LIVE}	TLM, 9 TRJ, 3 (2H.S., 1L.S.)
For Live + 2 SIM Missions (Up to four)					
A simulated launch included	Not applicable to Interim Model 3 - launch intervals preclude need for more than three concurrent operations.				
No simulated launch included					

TABLE B.3-IIC

SIMULTANEOUS VEHICLE SUPPORT REQUIREMENTS
Worst-Case Situations from M(P)-2A

CASES OF INTEREST	VEHICLES TO BE SUPPORTED: IN Launch	Inflight E.O. Vehicles	Inflight Lunar Vehicles	Lunar Surface Vehicles	Total No. of Vehicles
For Live Missions Only (Up to two) All missions; a launch included	SI SII SIVB LM EM CSM 500	CSM EM LM EM		EM	TLM, 11 TRJ, 3 — 1 LCH, 1 H.S, 1 L.S.
All missions; no launch included		LM EM CSM EM	CSM EM LM LUNAR DESCENT	EM	TLM, 8 TRJ, 4 — 2 H.S., 2 L.S
Any single mission (may be multi-flt)	SI SIVB CSM EM 200	LM EM CSM EM	Note: Same as for SR 500 Prime Model		TLM, 8 TRJ, 2 — 1 LCH, 1 L.S.
For LIVE + 1 SIM Mission (Up to three) A simulated launch included	SI SIVB CSM SIM 200	CSM LM EM EM	CSM LM EM	EM	TLM, 11 TRJ, 3 — 1 LCH, 2 H.S.
No simulated launch included		CSM LM EM EM LIVE CSM EM LM EM SIM	CSM EM LM LUNAR DESCENT LIVE	EM	TLM, 12 TRJ, 5 — 3 H.S., 2 L.S
For Live + 2 SIM Missions (Up to four) A simulated launch included	Not applicable - launch intervals preclude need for more than three concurrent operations (See Appendix B.2).				
No simulated launch included					

TABLE B.3-IID

SIMULTANEOUS VEHICLE SUPPORT REQUIREMENTS
Worst-Case Situations from ML-65-3

CASES OF INTEREST	VEHICLES TO BE SUPPORTED: In Launch	Inflight E.O. Vehicles	Inflight Lunar Vehicle	Lunar Surface Vehicles	Total No. of Vehicles
For Live Missions Only (Up to two) All missions; a launch included	Same as for M(P)-2A				
All missions; no launch included		CSM LM EM EM CSM EM	CSM EM LM LUNAR DESCENT	EM	TLM, 10 TRJ, 4 2.H.S. 2.L.S.
Any single mission (May be multi-flt)	Same as for M(P)-2A				
For Live + 1 SIM Mission (Up to three) A simulated launch included	Same as for M(P)-2A				
No simulated launch included	Same as for M(P)-2A				
For Live + 2 SIM Missions (UP to four) A simulated launch included	Same as for M(P)-2A				
No simulated launch included	Same as for M(P)-2A				

activity periods. Such scheduling, however, does not provide a solution to demand peaking if the duration of the peaking condition is such that relief may be found only beyond the point in time at which completion of the associated tasks is required. In such a case, one may not take advantage of the "valleys" without incurring schedule slippage. For these reasons, it is considered of design interest to compare the results of designing to average densities with the results of designing to peak densities. As further backup to a consideration of the peaking of computer hour demands, Appendix B.2 presents an analysis of peaking within a nominal program development and checkout cycle for mission programs.

Appendices A.2 and B.2 discuss the two different forms in which computer hours for direct mission support must be expressed to permit computer hour sizing for different RTCC organizations. The numbers found in Table B.3-III are taken directly from these appendices with the exception of the computer hour figures associated with the schedules when assuming peak flight density. Figures for the peak flight density case have been obtained by assuming that computer hours for live mission support are proportional to the flight density. This, in turn, assumes that the year for which the peak density was derived is characterized by the same average flight duration and the same degree of overlap between missions/flights as for the total schedule. These underlying assumptions appear reasonable. Note that all computer hour figures are based on the use of dynamic standby machines for critical phases. This technique avoids the necessity for separate computer hour figures for the dynamic standby and startup/startover cases; the resulting inaccuracy - a slight exaggeration of computer hour requirements for the startup/startover case - is considered negligible.

To assure that requirements combinations associate a realistic number of concurrent operations with each model or schedule rather than permitting academic combinations of requirements to exist, an upper bound on the number of concurrent operations has been established for each model and schedule. As such, this value constrains the process of combining values for different requirements variables. For example, an upper bound of three for M(P)-2A indicates that a value of four for the number of concurrent operations may <u>not</u> be combined with requirements values which are directly derivative from M(P)-2A. A specific upper bound on the number of concurrent operations has been derived by assuming a 45 day prelaunch period to encompass all SIM's and pad support and by determining the maximum number, for each model and schedule, of prelaunch periods which overlap two live operations.

Additional Combinations

Table B.3-III delineates six combinations of those requirements related to computer hours. Each of the six is associated with one of the four tables depicting worst case vehicle support situations; the correlation is dictated by the model or schedule involved. Additional combinations may be generated by considering the impact of slippages which, for M(P)-2A and ML-65-3, result in a different degree of mission/flight overlap and therefore, in a different value for instantaneous

TABLE B.3-III

VALUES FOR REQUIREMENTS AFFECTING
COMPUTER HOUR DEMANDS

Requirements Source	Maximum No. of Concurrent Operations	Flight Density (flights/year)		Computer Hrs/Mo for Live Mission Support	
		Average	Peak	Total for Mission Config.	Per Funct. Element[a]
SR 500 Prime Model	4	8	N.A.	444	264
SR 500 Interim Model #3	3	8	N.A.	444	384
M(P)-2A	3	8.4	-	503	461
		-	10.0	579	531
ML-65-3	3	11.4	-	451	402
		-	13.0	514	457

KEY: N.A. - Not Applicable

NOTE:

[a]Must be multiplied by 2 or 3 depending on which pure Function-Oriented or Launch/Function Hybrid configuration is being considered. For the Mission/Display Hybrid case, this figure represents the number of hours per month of actual mission support by the display processing element. The "mission" figure in the adjacent column represents the total for all mission elements in the Mission/Display case. Result: total Live mission support computer hour requirements for the Mission/Display case are calculated as the sum of the "total mission" figure and the "per functional element" figure.

loading (% CPU used). Analysis shows that certain schedule slippages in either planning schedule will result in worst-case simultaneous vehicle support situations identical to those derivative from the SR 500 Prime Model. To permit consideration of such slippages, four additional cases have been generated by viewing each schedule as occurring both with and without slippage. Modifications in the worst case vehicle support situation may be reflected by equating a schedule with slippage to the SR 500 Prime Model from an instantaneous loading viewpoint. As a corrollary, the maximum number of concurrent operations is considered to be equal to four when reflecting the impact of schedule slippage. The resulting total of ten cases to be "designed against" is represented in Table B.3-IV with a column added to specifically correlate each case with a set of worst-case vehicle support situations. For example, refer to case 3. The product of designing to this case would be a system which supports ML-65-3 assuming average flight density for computer hour sizing purposes and allowing for the impact of schedule slippage on vehicle support requirements. (See the "Description" column). Because schedule slippage is allowed, the third column references the SR 500 Prime Model for determining vehicle support requirements. Other columns are identical to those appearing in Table B.3-III.

TOTAL REQUIREMENTS SPECTRUM

Because the "values" for the simultaneous vehicle support requirement are implied by Table B.3-IV, the total spectrum of requirements combinations may be viewed simply as all legitimate combinations of the ten Table B.3-IV cases with the fourteen combinations of Step 2 variables delineated in Table B.3-I. Noting that the upper bound on the number of concurrent operations constrains the number of legitimate combinations as described above, a total complement of one hundred and fifteen (115) combinations of requirements may be established. A design must be developed for each combination in order to fulfill the objective of investigating costs over a spectrum of requirements. Of course, different requirements combinations are of interest only to the extent that they demand significantly different RTCC support; one would expect a comparison of design results to lead to the elimination from further consideration of all but those combinations for which costs may be clearly distinguished.

TABLE B.3-IV

REQUIREMENTS COMBINATIONS DERIVATIVE FROM MODELS/SCHEDULES

CASE		Model or Schedule for Reference to Vehicle Support Tables	Maximum No. of Concurrent Operations	Flights/Yr.	Computer Hours/Month for LIVE Mission Support	
ID	Description				Total for Mission Configuration	Per Functional Element
1	ML-65-3 with slippage, Peak density	SR 500 Prime Model	4	13	514	457
2	ML-65-3 without slippage, Peak density	ML-65-3	3	13	514	457
3	ML-65-3 with slippage, Average density	SR 500 Prime Model	4	11.4	451	402
4	ML-65-3 without slippage, Average density	ML-65-3	3	11.4	451	402
5	M(P)-2A with slippage, Peak density	SR 500 Prime Model	4	10	579	531
6	M(P)-2A without slippage, Peak Density	M(P)-2A	3	10	579	531
7	M(P)-2A with slippage, Average density	SR 500 Prime Model	4	8.4	503	461
8	M(P)-2A without slippage, Average density	M(P)-2A	3	8.4	503	461
9	SR 500 Prime Model	SR 500 Prime Model	4	8	444	264
10	SR 500 Interim Model #3	Interim Model #3	3	8	444	384

APPENDIX B.4

DEVELOPMENT OF DESIGN RESULTS

INTRODUCTION

Appendix B.3 identifies all requirements combinations for which design results are to be developed in support of the original design objectives. This appendix addresses itself to the tools, techniques and assumptions required to translate requirements into design results, the application of these and the results achieved. The treatment of tools, techniques and assumptions represents a further detailing of information contained in Appendix B.1. Their application is described by relating step-by-step progress through the Figure B.1-1 design process to the matrix of design results achieved, Table B.4-I.

Before proceeding, some general comments about the initial design results should be made. Firstly, no provisions have been made for the incorporation of "computerized tools" within the RTCC; discussions with Flight Control Division personnel (Operations Analysis Branch) indicate that the requirements for such tools have not yet become definitive enough to permit any quantitative design consideration. More importantly, two important users of computer resources have been neglected for purposes of generating the results tabulated in Table B.4-I. Specifically, neither the Auxiliary Computing Room (ACR) nor the Ground Simulation Support Computer (GSSC) are included as separate machines in the direct mission support results or as computer hour users when sizing the total machine complement. These omissions exist because quantitative sizing estimators for GSSC and ACR requirements are not yet fully developed and because questions of integration versus non-integration with the RTCC favor treatment as a later addition rather than detailed incorporation in each design result. Note, however, that these omissions apply only to the results presented in Table B.4-I. Appendix B.5 includes a discussion of how ACR and GSSC requirements should be considered when viewing the Table B.4-I results within a total data handling context.

MATRIX OF DESIGN RESULTS

Table B.4-I constitutes a matrix of the design results achieved by proceeding through the Figure B.1-1 process on a step-by-step basis. Before describing the manner in which individual design steps contribute to the matrix results, the matrix itself must be understood.

For a given combination of requirements, the matrix is constructed to facilitate a comparison between the design results associated with different RTCC organization schemes. This is achieved by defining column headings such that a single row completely describes a single combination of requirements and presents all design results related to that requirements combination. The 115 rows of the matrix represent the 115 combinations of requirements which constitute the total "requirements spectrum". Each combination is defined as follows: Column (1) simply provides a row identifier, columns (2) through (5) directly express a value for certain requirements variables, and column (6) implies a unique value for each of the remaining requirements variables by referencing one of the ten (10) cases delineated in Table B.3-IV.

Six groups of three columns each present design results (columns (7) through (24)) where each group describes the results for a particular RTCC organization alternative. (Six rather than eight such groups appear because, as discussed below in more detail, two functional allocation schemes may be immediately rejected based on loading results.) Within each group of three columns, column headings may be correlated as follows with design steps:

COLUMN HEADING	CONTRIBUTING DESIGN STEPS
Machines for LIVE and SIM Mission Support Only (# and Type)*	2 and 3
Total Machine Complement Reflecting Computer Hours	4
$/Month Rental	5

*The term "direct support configuration" is adopted hereafter as a short-hand version of "Machines for LIVE & SIM Mission Support Only (# and Type)."

Thus the 115 rows represent the requirements spectrum considered and all design results for a given point in that spectrum are contained in a single row.

Note that Table B.4-I has been provided solely as a convenient format for recording the results of proceeding through the design process. As such, Table B.4-I is too voluminous and too detailed to permit easy identification of the most important characteristics, trends, relationships, etc., associated with the final design results. Appendix B.5 must be consulted for a summarization and discussion of these results.

DESIGN DEVELOPMENT

Subsequent paragraphs are organized in accordance with the step-by-step structure of the Figure B.1-1 design process. Emphasis is on the tools, techniques and assumptions which support each design step; their specification and their use.

Determination of the Number of Required Mission Support Machines
(Reference Step 2 of design process)

As discussed briefly in Appendix B.1, an assumed "redundancy ratio" is required to translate Step 2 requirements values into the number of machines required for direct mission support. Defining this ratio specifically as the number of mission processing machines divided by the number of Startup/Startover or backup machines, a 2:1 ratio has been

Table B.4-I MATRIX OF DESIGN RESULTS

REQUIREMENTS COMBINATIONS						DESIGN RESULTS: PURE MISSION			PURE FN: TLM-TRJ			PURE FN: TLM-TRJ-DISP			LCH/FN HYBRID: TLM-TRJ-LAUNCH			LCH/FN HYBRID: TLM-TRJ-DISP-LAUNCH			MISS/DISP HYBRID		
RQMTS COMB. ID (1)	TYPE OF CRIT PH BACKUP (2)	# SIMULT CRIT PHS (3)	TYPE OF CRIT PH (Applies to LCH/FN Only) (4)	# CONCURRENT OPS (5)	TABLE CASE ID (6)	MACHINES FOR LIVE & SIM MISS SUPPORT ONLY (# & TYPE) (7)	TOTAL MACH COMPLEMENT REFLECTING COMP HRS (# & TYPE) (8)	$/MO RENTAL (TOTAL) (9)	MACHINES FOR LIVE & SIM MISS SUPPORT ONLY (# & TYPE) (10)	TOTAL MACH COMPLEMENT REFLECTING COMP HRS (# & TYPE) (11)	$/MO RENTAL (TOTAL) (12)	MACHINES FOR LIVE & SIM MISS SUPPORT ONLY (# & TYPE) (13)	TOTAL MACH COMPLEMENT REFLECTING COMP HRS (# & TYPE) (14)	$/MO RENTAL (TOTAL) (15)	MACHINES FOR LIVE & SIM MISS SUPPORT ONLY (# & TYPE) (16)	TOTAL MACH COMPLEMENT REFLECTING COMP HRS (# & TYPE) (17)	$/MO RENTAL (TOTAL) (18)	MACHINES FOR LIVE & SIM MISS SUPPORT ONLY (# & TYPE) (19)	TOTAL MACH COMPLEMENT REFLECTING COMP HRS (# & TYPE) (20)	$/MO RENTAL (TOTAL) (21)	MACHINES FOR LIVE & SIM MISS SUPPORT ONLY (# & TYPE) (22)	TOTAL MACH COMPLEMENT REFLECTING COMP HRS (# & TYPE) (23)	$/MO RENTAL (TOTAL) (24)
1	DSC	2	With LCH	4	1	7 - 75J's	8-7 75J's, 1 50I's	809K	4 - 75I's	9-8 75I's, 1 50I	759K	6-4 75I's, 2 65I's	10-6 75I's, 2 65I's, 2 50I's	780K	6-2 75J's, 4 75I's	9-2 75J's, 6 75I's, 1 50I	799K	8-2 75J's, 4 75I's, 2 65I's	10-2 75J's, 4 75I's, 2 65I's, 2 50I's	820K	9-2 75I's, 7 65I's	10-2 75I's, 7 65I's, 1 50I	786K
2					3	"	7-7 75J's	770K	"	8-7 75I's, 1 50I	669K	"	9-7 75I's, 2 50I's	708K	"	8-2 75J's, 5 75I's, 1 50I	709K	"	9-2 75J's, 4 75I's, 2 65I's, 1 50I	781K	"	9-2 75I's, 7 65I's	747K
3					5	"	"	"	"	"	"	"	9-6 75I's, 2 65I's, 1 50I	741K	"	"	"	"	"	"	"	"	"
4					7	"	"	"	"	7-6 75I's, 1 50I	579K	"	8-5 75I's, 2 65I's, 1 50I	651K	"	7-2 75J's, 4 75I's, 1 50I	619K	"	8-2 75J's, 4 75I's, 2 65I's	742K	"	"	"
5					9	"	"	"	"	6-5 75I's, 1 50I	489K	"	6-4 75I's, 2 65I's	522K	"	6-2 75J's, 4 75I's	580K	"	"	"	"	"	"
6				3	1	6 - 75J's	8-7 75J's, 1 50I's	809K	4 - 75I's	9-8 75I's, 1 50I	759K	6-4 75I's, 2 65I's	10-6 75I's, 2 65I's, 2 50I	780K	"	9-2 75J's, 6 75I's, 1 50I	799K	8-2 75J's, 4 75I's, 2 65I's	10-2 75J's, 4 75I's, 2 65I's, 2 50I's	820K	8-2 75I's, 6 65I's	9-8 75I's, 1 50I	759K
7					2	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
8					3	"	7-6 75J's, 1 50I's	699K	"	8-7 75I's, 1 50I	669K	"	9-7 75I's, 2 50I's	708K	"	8-2 75J's, 5 75I's, 1 50I	709K	"	9-2 75J's, 4 75I's, 2 65I's, 1 50I	781K	"	9-2 75I's, 6 65I's, 1 50I	705K
9					4	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
10					5	"	"	"	"	"	"	"	9-6 75I's, 2 65I's, 1 50I	741K	"	"	"	"	"	"	"	"	"
11					6	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
12					7	"	6-75J's	660K	"	7-6 75I's, 1 50I's	579K	"	8-5 75I's, 2 65I's, 1 50I	651K	"	7-2 75J's, 4 75I's, 1 50I	619K	"	8-2 75J's, 4 75I's, 2 65I's	742K	"	8-2 75I's, 6 65I's	666K
13					8	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
14					9	"	"	"	"	6-5 75I's, 1 50I's	489K	"	6-4 75I's, 2 65I's	522K	"	6-2 75J's, 4 75I's	580K	"	"	"	"	"	"
15					10	"	"	"	"	7-5 75I's, 2 50I's	528K	6-2 75I's, 4 65I's	7-4 75I's, 2 65I's, 1 50I	561K	"	"	"	8-2 75J's, 2 75I's, 4 65I's	8-2 75J's, 2 75I's, 4 65I's	724K	"	"	"
16				2	1	4 - 75J's	8-5 75J's, 2 75I's, 1 50I	769K	"	9-8 75I's, 1 50I	759K	6-4 75I's, 2 65I's	10-6 75I's, 2 65I's, 2 50I	780K	"	9-2 75J's, 6 75I's, 1 50I	799K	8-2 75J's, 2 75I's, 4 65I's	10-2 75J's, 2 75I's, 4 65I's, 2 50I's	802K	6-2 75I's, 4 65I's	9-3 75I's, 5 65I's, 1 50I	714K
17					2	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
18					3	"	7-4 75J's, 2 75I's, 1 50I	659K	"	8-7 75I's, 1 50I	669K	"	9-7 75I's, 2 50I's	708K	"	8-2 75J's, 5 75I's, 1 50I	709K	"	9-2 75J's, 2 75I's, 4 65I's, 1 50I	763K	"	8-7 75I's, 1 50I	669K
19					4	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
20					5	"	"	"	"	"	"	"	9-6 75I's, 2 65I's, 1 50I	741K	"	"	"	"	"	"	"	"	"
21					6	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
22					7	"	6-5 75J's, 1 50I's	589K	"	7-6 75I's, 1 50I	579K	"	8-5 75I's, 2 65I's, 1 50I	651K	"	7-2 75J's, 4 75I's, 1 50I	619K	"	8-2 75J's, 2 75I's, 4 65I's	724K	"	7-6 75I's, 1 50I	579K
23					8	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
24					9	"	"	"	"	6-5 75I's, 1 50I	489K	"	6-4 75I's, 2 65I's	522K	"	6-2 75J's, 4 65I's	580K	"	"	"	"	6-6 75I's	540K
25					10	"	"	"	"	7-5 75I's, 2 50I's	528K	6-2 75I's, 4 65I's	7-4 75I's, 2 65I's, 1 50I	561K	6-2 75J's, 2 75I's, 2 65I's	6-2 75J's, 2 75I's, 2 65I's	562K	"	"	"	"	"	"
26		1	With LCH	4	1	7 - 75J's	8-7 75J's, 1 50I's	809K	"	9-8 75I's, 1 50I	759K	6-4 75I's, 2 65I's	10-6 75I's, 2 65I's, 2 50I	780K	5-2 75J's, 3 75I's	9-2 75J's, 6 75I's, 1 50I	799K	7-2 75J's, 3 75I's, 2 65I's	10-2 75J's, 4 75I's, 2 65I's, 2 50I's	820K	9-2 75I's, 7 65I's	10-2 75I's, 7 65I's, 1 50I	786K
27			(or 2		3	"	7 - 7 75J's	770K	"	8-7 75I's, 1 50I	669K	"	9-7 75I's, 2 50I's	708K	"	8-2 75J's, 5 75I's, 1 50I	709K	"	9-2 75J's, 5 75I's, 2 50I's	748K	"	9-2 75I's, 7 65I's	747K
28			Simult. Crit		5	"	"	"	"	"	"	"	9-6 75I's, 2 65I's, 1 50I	741K	"	"	"	"	9-2 75J's, 3 75I's, 3 65I's, 1 50I	772K	"	"	"
29			Phases		7	"	"	"	"	7-6 75I's, 1 50I	579K	"	8-5 75I's, 2 65I's, 1 50I	651K	"	7-2 75J's, 4 75I's, 1 50I	619K	"	8-2 75J's, 3 75I's, 2 65I's, 1 50I	691K	"	"	"
30			without LCH)		9	"	"	"	"	6-5 75I's, 1 50I	489K	"	6-4 75I's, 2 65I's	522K	"	6-2 75J's, 3 75I's, 1 50I	529K	"	7-2 75J's, 3 75I's, 2 65I's	652K	"	"	"
31				3	1	5 - 75J's	8-5 75J's, 2 75I's, 1 50I	769K	"	9-8 75I's, 1 50I	759K	"	10-6 75I's, 2 65I's, 2 50I	780K	"	9-2 75J's, 6 75I's, 1 50I	799K	"	10-2 75J's, 4 75I's, 2 65I's, 2 50I's	820K	7-2 75I's, 5 65I's	9-3 75I's, 5 65I's, 1 50I	714K
32					2	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
33					3	"	7-6 75J's, 1 50I's	699K	"	8-7 75I's, 1 50I	669K	"	9-7 75I's, 2 50I's	708K	"	8-2 75J's, 5 75I's, 1 50I	709K	"	9-2 75J's, 5 75I's, 2 50I's	748K	"	8-7 75I's, 1 50I	669K
34					4	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
35					5	"	"	"	"	"	"	"	9-6 75I's, 2 65I's, 1 50I	741K	"	"	"	"	9-2 75J's, 3 75I's, 3 65I's, 1 50I	772K	"	"	"
36					6	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
37					7	"	6-5 75J's, 1 50I's	589K	"	7-6 75I's, 1 50I	579K	"	8-5 75I's, 2 65I's, 1 50I	651K	"	7-2 75J's, 4 75I's, 1 50I	619K	"	8-2 75J's, 3 75I's, 2 65I's, 1 50I	691K	"	7 - 7 75I's	630K
38					8	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
39					9	"	"	"	"	6-5 75I's, 1 50I	489K	"	6-4 75I's, 2 65I's	522K	"	6-2 75J's, 3 75I's, 1 50I	529K	"	7-2 75J's, 3 75I's, 2 65I's	652K	"	7-2 75I's, 5 65I's	585K
40					10	"	"	"	"	7-5 75I's, 2 50I's	528K	6-2 75I's, 4 65I's	7-4 75I's, 2 65I's, 1 50I	561K	"	6-2 75J's, 4 75I's	580K	" " 2 75I's, 3 65I's	7-2 75J's, 2 75I's, 3 65I's	643K	"	"	"
41				2	1	4 - 75J's	8-5 75J's, 2 75I's, 1 50I	769K	"	9-8 75I's, 1 50I	759K	"	10-6 75I's, 2 65I's, 2 50I's	780K	"	9-2 75J's, 6 75I's, 1 50I	799K	7-2 75I's, 2 75I's, 3 65I's	10-2 75J's, 2 75I's, 4 65I's, 2 50I's	802K	6-2 75I's, 4 65I's	9-3 75I's, 5 65I's, 1 50I	714K
42					2	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
43					3	"	7-4 75J's, 2 75I's, 1 50I	659K	"	8-7 75I's, 1 50I	669K	"	9-7 75I's, 2 50I's	708K	"	8-2 75J's, 5 75I's, 1 50I	709K	"	9-2 75J's, 2 75I's, 3 65I's, 2 50I's	721K	"	8-7 75I's, 1 50I	669K
44					4	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
45					5	"	"	"	"	"	"	"	9-6 75I's, 2 65I's, 1 50I	741K	"	"	"	"	9-2 75J's, 2 75I's, 4 65I's, 1 50I	763K	"	"	"
46					6	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
47					7	"	6-5 75J's, 1 50I	589K	"	7-6 75I's, 1 50I	579K	"	8-5 75I's, 2 65I's, 1 50I	651K	"	7-2 75J's, 4 75I's, 1 50I	619K	"	8-2 75J's, 2 75I's, 3 65I's, 1 50I	682K	"	7-6 75I's, 1 50I	579K
48					8	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
49					9	"	"	"	"	6-5 75I's, 1 50I	489K	"	6-4 75I's, 2 65I's	522K	"	6-2 75J's, 3 75I's, 1 50I	529K	"	7-2 75J's, 2 75I's, 3 65I's	643K	"	6-6 75I's	540K
50					10	"	"	"	"	7-5 75I's, 2 50I's	528K	6-2 75I's, 4 65I's	7-4 75I's, 2 65I's, 1 50I	561K	"	6-2 75J's, 4 75I's	580K	"	"	"	"	"	"
51		0	NA	4	1	6 - 75J's	8-7 75J's, 1 50I	809K													8-2 75I's, 6 65I's	9-8 75I's, 1 50I	759K
52					3	"	7-6 75J's, 1 50I	699K													"	9-2 75I's, 6 65I's, 1 50I	705K
53					5	"	"	"													"	"	"
54					7	"	6-6 75J's	660K													"	8-2 75I's, 6 65I's	666K
55					9	"	"	"													"	"	"
56		0	NA	3	1	5-5 75J's	8-5 75J's, 2 75I's, 1 50I	769K													6-2 75I's, 4 65I's	9-3 75I's, 5 65I's, 1 50I	714K
57					2	"	"	"													"	"	"
58					3	"	7-6 75J's, 1 50I	699K					Not Applicable								"	8-7 75I's, 1 50I	669K
59					4	"	"	"													"	"	"
60					5	"	"	"													"	"	"
61					6	"	"	"													"	"	"
62					7	"	6-5 75J's, 1 50I	589K													"	7-6 75I's, 1 50I	579K
63					8	"	"	"													"	"	"
64					9	"	"	"													"	6-6 75I's	540K
65					10	"	"	"													"	"	"
66	STARTUP	2	WITH LAUNCH	4	1	6-6 75J's	8-7 75J's, 1 50I	809K	3 - 75I's	9-8 75I's, 1 50I	759K	5-3 75I's, 2 65I's	10-6 75I's, 2 65I's, 2 50I's	780K	5-2 75J's, 3 75I's	9-2 75J's, 6 75I's, 1 50I	799K	6-2 75J's, 4 75I's	10-2 75J's, 4 75I's, 2 65I's, 2 50I's	820K	8-2 75I's, 6 65I's	9-8 75I's, 1 50I	759K
67					3	"	7-6 75J's, 1 50I	699K	"	8-7 75I's, 1 50I	669K	"	9-7 75I's, 2 50I's	708K	"	8-2 75J's, 5 75I's, 1 50I	709K	"	9-2 75J's, 5 75I's, 2 50I's	748K	"	9-2 75I's, 6 65I's, 1 50I	705K
68					5	"	"	"	"	"	"	"	9-6 75I's, 2 65I's, 1 50I	741K	"	"	"	"	9-2 75J's, 4 75I's, 2 65I's, 1 50I	781K	"	"	"
69					7	"	6-6 75J's	660K	"	7-6 75I's, 1 50I	579K	"	8-5 75I's, 2 65I's, 1 50I	651K	"	7-2 75J's, 4 75I's, 1 50I	619K	"	8-2 75J's, 5 75I's, 1 50I	709K	"	8-2 75I's, 6 65I's	666K
70					9	"	"	"	"	6-5 75I's, 1 50I	489K	"	7-3 75I's, 2 65I's, 2 50I's	510K	"	6-2 75J's, 3 75I's, 1 50I	529K	"	6-2 75J's, 4 75I's	580K	"	"	"
71				3	1	5-5 75J's	8-5 75J's, 2 75I's, 1 50I	769K	"	9-8 75I's, 1 50I	759K	"	10-6 75I's, 2 65I's, 2 50I's	780K	"	9-2 75J's, 6 75I's, 1 50I	799K	"	10-2 75J's, 4 75I's, 2 65I's, 2 50I's	820K	6-2 75I's, 4 65I's	9-3 75I's, 5 65I's, 1 50I	714K
72					2	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
73					3	"	7-6 75J's, 1 50I	659K	"	8-7 75I's, 1 50I	669K	"	9-7 75I's, 2 50I's	708K	"	8-2 75J's, 5 75I's, 1 50I	709K	"	9-2 75J's, 5 75I's, 2 50I's	748K	"	8-7 75I's, 1 50I	669K
74					4	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
75					5	"	"	"	"	"	"	"	9-6 75I's, 2 65I's, 1 50I	741K	"	"	"	"	9-2 75J's, 4 75I's, 2 65I's, 1 50I	781K	"	"	"
76					6	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
77					7	"	6-5 75J's, 1 50I	589K	"	7-6 75I's, 1 50I	579K	"	8-5 75I's, 2 65I's, 1 50I	651K	"	7-2 75J's, 4 75I's, 1 50I	619K	"	8-2 75J's, 5 75I's, 1 50I	709K	"	7-6 75I's, 1 50I	579K
78					8	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
79					9	"	"	"	"	6-5 75I's, 1 50I	489K	"	7-3 75I's, 2 65I's, 2 50I's	510K	"	6-2 75J's, 3 75I's, 1 50I	529K	"	6-2 75J's, 4 75I's	580K	"	6-6 75I's	540K
80					10	"	"	"	"	7-5 75I's, 2 50I's	528K	" - 2 75I's, 3 65I's	7-3 75I's, 3 65I's, 1 50I	552K	"	6-2 75J's, 4 75I's	580K	"	7-2 75J's, 4 75I's, 1 50I	619K	"	"	"

TABLE B4-I (Continued)

REQUIREMENTS COMBINATIONS						DESIGN RESULTS: PURE MISSION			PURE FN: TLM-TRJ			PURE FN: TLM-TRJ-DISP			LCH/FN HYBRID: TLM-TRJ-LAUNCH			LCH/FN HYBRID: TLM-TRJ-DISP-LAUNCH			MISS/DISP HYBRID		
RQMTS COMB. ID (1)	TYPE OF CRIT PH. BACKUP (2)	# SIMULT CRIT PHS (3)	TYPE OF CRIT PH (Applies to LCH/FN Only) (4)	# CONCUR-RENT OPS. (5)	TABLE CASE ID (6)	MACHINES FOR LIVE & SIM MISS SUPPORT ONLY (# & TYPE) (7)	TOTAL MACH COMPLE-MENT REFLECTING COMP. HRS (# & TYPE) (8)	$/MO RENTAL (TOTAL) (9)	MACHINES FOR LIVE & SIM MISS SUPPORT ONLY (# & TYPE) (10)	TOTAL MACH COMPLE-MENT REFLECTING COMP HRS (# & TYPE) (11)	$/MO RENTAL (TOTAL) (12)	MACHINES FOR LIVE & SIM MISS SUPPORT ONLY (# & TYPE) (13)	TOTAL MACH COMPLE-MENT REFLECTING COMP HRS (# & TYPE) (14)	$/MO RENTAL (TOTAL) (15)	MACHINES FOR LIVE & SIM MISS SUPPORT ONLY (# & TYPE) (16)	TOTAL MACH COMPLE-MENT REFLECTING COMP HRS (# & TYPE) (17)	$/MO RENTAL (TOTAL) (18)	MACHINES FOR LIVE & SIM MISS SUPPORT ONLY (# & TYPE) (19)	TOTAL MACH COMPLE-MENT REFLECTING COMP HRS (# & TYPE) (20)	$/MO RENTAL (TOTAL) (21)	MACHINES FOR LIVE & SIM MISS SUPPORT ONLY (# & TYPE) (22)	TOTAL MACH COMPLE-MENT REFLECTING COMP HRS (# & TYPE) (23)	$/MO RENTAL (TOTAL) (24)
81	STARTUP	2	WITH LAUNCH	2	1	3 - 3 75J's	8-5 75J's, 2 75I's, 1 50I	769K	3-3-75I's	9-8 75I's, 1 50I	759K	5-3 75I's, 2 65I's	10-6 75I's, 2 65I's, 2 50I's	780K	5-2 75J's, 3 75I's	9-2 75J's, 6 75I's, 1 50I	799K	6-2 75J's, 4 75I's	10-2 75J's, 4 75I's, 2 65I's, 2 50I's	820K	5-2 75I's, 3 65I's	9-3 75I's, 5 65I's, 1 50I	714K
82					2	"	"	"	"	"	"	"			"	"	"	"			"	"	"
83					3	"	7-4 75J's, 2 75I's, 1 50I	659K	"	8-7 75I's, 1 50I	669K	"	9-7 75I's, 2 50I's	708K	"	8-2 75I's, 5 75I's, 1 50I	709K	"	9-2 75J's, 5 75I's, 2 50I's	748K	"	8-3 75I's, 4 65I's, 1 50I	633K
84					4	"	"	"	"	"	"	"			"	"		"			"	"	"
85					5	"	"	"	"	"	"	"	9-6 75I's, 2 65I's, 1 50I	741K	"	"		"	9-2 75J's, 4 75I's, 2 65I's, 1 50I	781K	"	"	"
86					6	"	"	"	"	"	"	"			"	"		"			"	"	"
87					7	"	6-5 75J's, 1 50I	589K	"	7-6 75I's, 1 50I	579K	"	8-5 75I's, 2 65I's, 1 50I	651K	"	7-2 75J's, 4 75I's, 1 50I	619K	"	8-2 75J's, 5 75I's, 1 50I	709K	"	7-3 75I's, 3 65I's, 1 50I	552K
88					8	"	"	"	"	"	"	"			"			"			"	"	"
89					9	"	"	"	"	6-5 75I's, 1 50I	489K	"	7-3 75I's, 2 65I's, 2 50I's	510K	"	6-2 75J's, 3 75I's, 1 50I	529K	"	6-2 75J's, 4 75I's	580K	"	6-5 75I's, 1 50I	489K
90					10	"	"	"	"	7-5 75I's, 2 50I's	528K	" - 2 75I's, 3 65I's	7-3 75I's, 3 65I's, 1 50I	552K	"	6-2 75J's, 4 75I's	580K	"	7-2 75J's, 4 75I's, 1 50I	619K	"	6-3 75I's, 3 65I's	512K
91				4	1	6 - 6 75J's	8-7 75J's, 1 50I	809K	3 - 3 75I's	9-8 75I's, 1 50I	759K	5-3 75I's, 2 65I's	10-6 75I's, 2 65I's, 2 50I's	780K	"	9-2 75J's, 6 75I's, 1 50I	799K	"	10-2 75J's, 4 75I's, 2 65I's, 2 50I's	820K	8-2 75I's, 6 65I's	9-8 75I's, 1 50I	759K
92					3	"	7-6 75J's, 1 50I	699K	"	8-7 75I's, 1 50I	669K	"	9-7 75I's, 2 50I's	708K	"	8-2 75J's, 5 75I's, 1 50I	709K	"	9-2 75J's, 5 75I's, 2 50I's	748K	"	9-2 75I's, 6 65I's, 1 50I	705K
93					5	"	"	"	"	"	"	"	9-6 75I's, 2 65I's, 1 50I	741K	"	"	"	"	9-2 75J's, 4 75I's, 2 65I's, 1 50I	781K	"	"	"
94					7	"	6 - 6 75J's	660K	"	7-6 75I's, 1 50I	579K	"	8-5 75I's, 2 65I's, 1 50I	651K	"	7-2 75I's, 4 75I's, 1 50I	619K	"	8-2 75J's, 5 75I's, 1 50I	709K	"	8-2 75I's, 6 65I's	666K
95					9	"	"	"	"	6-5 75I's, 1 50I	489K	"	7-3 75I's, 2 65I's, 2 50I	510K	"	6-2 75I's, 3 75I's, 1 50I	529K	"	6-2 75J's, 4 75I's	580K	"	"	"
96				3	1	5 - 6 75J's	8-5 75J's, 2 75I's, 1 50I	769K	3 - 3 75I's	9-8 75I's, 1 50I	759K	"	10-6 75I's, 2 65I's, 2 50I's	780K	"	9-2 75I's, 6 75I's, 1 50I	799K	"	10-2 75J's, 4 75I's, 2 65I's, 2 50I's	820K	6-2 75I's, 4 65I's	9-3 75I's, 5 65I's, 1 50I	714K
97					2	"	"	"	"	"		"	"	"	"	"	"	"	"	"	"	"	"
98					3	"	7-6 75J's, 1 50I	699K	"	8-7 75I's, 1 50I	669K	"	9-7 75I's, 2 50I's	708K	"	8-2 75J's, 5 75I's, 1 50I	709K	"	9-2 75J's, 5 75I's, 2 50I's	748K	"	8-7 75I's, 1 50I	669K
99					4	"	"	"	"	"	"	"	"	"	"	"	"	"	"		"	"	"
100					5	"	"	"	"	"	"	"	9-6 75I's, 2 65I's, 1 50I	741K	"	"	"	"	9-2 75J's, 4 75I's, 2 65I's, 1 50I	781K	"	"	"
101					6	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
102					7	"	6-5 75J's, 1 50I	589K	"	7-6 75I's, 1 50I	579K	"	8-5 75I's, 2 65I's, 1 50I	651K	"	7-2 75I's, 4 75I's, 1 50I	619K	"	8-2 75J's, 5 75I's, 1 50I	709K	"	7-6 75I's, 1 50I	579K
103					8	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
104					9	"	"	"	"	6-5 75I's, 1 50I	489K	"	7-3 75I's, 2 65I's, 2 50I's	510K	"	6-2 75J's, 3 65I's, 1 50I	519K	"	6-2 75J's, 4 75I's	580K	"	6-6 75I's	540K
105					10	"	"	"	"	7-5 75I's, 2 50I's	528K	" 2 75I's, 3 65I's	7-3 75I's, 3 65I's, 1 50I's	552K	"	6-2 75J's, 4 75I's	580K	"	7-2 75J's, 4 75I's, 1 50I	619K	"	"	"
106				2	1	3 - 3 75J's	8-5 75J's, 2 75I's, 1 50I	769K	3 - 3 75I's	9-8 75I's, 1 50I	759K	"	10-6 75I's, 2 65I's, 2 50I's	780K	"	9-2 75J's, 6 75I's, 1 50I	799K	"	10-2 75J's, 4 75I's, 2 65I's, 2 50I's	820K	5-2 75I's, 3 65I's	9-3 75I's, 5 65I's, 1 50I	714K
107					2	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
108					3	"	7-4 75J's, 2 75I's, 1 50I	659K	"	8-7 75I's, 1 50I	669K	"	9-7 75I's, 2 50I's	708K	"	8-2 75J's, 5 75I's, 1 50I	709K	"	9-2 75J's, 5 75I's, 2 50I's	748K	"	8-3 75I's, 4 65I's, 1 50I	633K
109					4	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
110					5	"	"	"	"	"	"	"	9-6 75I's, 2 65I's, 1 50I	741K	"	"	"	"	9-2 75J's, 4 75I's, 2 65I's, 1 50I	781K	"	"	"
111					6	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
112					7	"	6-5 75J's, 1 50I	589K	"	7-6 75I's, 1 50I	579K	"	8-5 75I's, 2 65I's, 1 50I	651K	"	7-2 75J's, 4 75I's, 1 50I	619K	"	8-2 75J's, 5 75I's, 1 50I	709K	"	7-3 75I's, 3 65I's, 1 50I	552K
113					8	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
114					9	"	"	"	"	6-5 75I's, 1 50I	489K	"	7-3 75I's, 2 65I's, 2 50I	510K	"	6-2 75J's, 3 75I's, 1 50I	529K	"	6-2 75J's, 4 75I's	580K	"	6-5 75I's, 1 50I	489K
115					10	"	"	"	"	7-5 75I's, 2 50I's	528	" 2 75I's, 3 65I's	7-3 75I's, 3 65I's, 1 50I	552K	"	6-2 75J's, 4 75I's	580K	"	7-2 75J's, 4 75I's, 1 50I	619K	"	6-3 75I's, 3 65I's	512K

assumed. This ratio is applied to the provision of backup for all computing elements when dynamic standby backup for critical phases is not required and for only those elements not supporting critical phases when dynamic standby backup for critical phases is required. A dynamic standby machine may not serve double duty as a startup/startover type of backup element.

Employment of the "redundancy ratio" as described permits a determination of the number of mission support machines required. As an example, consider the adoption of a purely mission-oriented system organization to satisfy the requirement for four concurrent operations, two simultaneous critical phases, and dynamic standby backup for critical phases. Seven machines are required as follows:

$\boxed{M_1}$ $\boxed{M_2}$ $\boxed{M_3}$ $\boxed{M_4}$

$\boxed{\text{DSC } M_1}$ $\boxed{\text{DSC } M_2}$ $\boxed{\text{Backup } (M_3 \text{ \& } M_4)}$

M_X = Mission or Operation "X"

"Backup" refers to Startup/Startover type of redundancy

Determination of Machine Types
(Reference Step 3 of design process)

The Step 3 task is to convert the number of direct mission support machines into a specific complement of Series 360 machines. To facilitate rapid "passes" through the design process, this task has been approached by developing design "building blocks" which directly yield a Series 360 model number (for each computer in the configuration) once the following have been defined: the model or schedule of interest, the number of concurrent operations being assumed, the RTCC organization alternative being considered and the particular element within that organization being sized.

Table B.4-II tabulates the design "building blocks" which have been constructed. The model or schedule of interest and the number of concurrent operations combine to define a column in Table B.4-II. The RTCC organization alternative being considered and the particular element therein being sized combine to define a row. The numerical entry appearing in each row/column intersection represents loading in terms of the %CPU time used when the CPU is a 360/75. The presence or lack of special symbology enclosing the numerical entries indicates the Series 360 machine model required. (See key associated with the table for further explanation.)

As a first step in generating the Table B.4-II loading entries, the worst-case vehicle support situations delineated in Table B.3-II, Appendix B.3, were translated into telemetry and trajectory-related processing tasks to be performed by a particular computing element. RTCC loading estimators as developed in Appendix A.3 and as summarized in Table B.4-III were then employed to achieve the final numerical entries in Table B.4-II. For example, 36.32% of a 360/75 TLM processing

Table B.4-II *SIZING BUILDING BLOCKS;* *
% CPU TIME USED (CPU = 360/75) & MACHINE MODELS REQUIRED FOR VARIOUS VEHICLE SUPPORT CASES

DEFINITION OF THE ELEMENT TO BE SIZED			DEFINITION OF THE VEHICLE SUPPORT CASES OF INTEREST (Worst-Case Derivatives from the Models and Schedules)												
			For SR 500 Prime Model				For ML-65-3			For M(P)-2A			For SR500 Int.Model 3		
				# Concurrent Operations				# Concurrent Operations			# Concurrent Operations			# Concurrent Operations	
Type of RTCC Organization	Specific RTCC Organization Alternative	Processing Element of Interest	Single Mission	2	3 (2)	4 (2)	Single Mission	2	3 (2)	Single Mission	2	3 (2)	Single Mission	2	3 (2)
Mission-Oriented	Standalone	MISSION $_{D,L}$	77.97%	N.A	N.A.	N.A.	SAME AS PRIME	N.A.	N.A.	SAME AS PRIME	N.A.	N.A.	SAME AS PRIME	N.A.	N.A.
Function-Oriented (functional elements support launches)	TLM-TRJ	TLM $_{D,L}$	N.A.	97.06%	→	→	N.A.	82.05%	95.49%	N.A.	80.18%	95.49%	N.A.	65.86%	69.61%
		TRJ $_{D,L}$ (3)	"	28.15	36.98	→	"	28.14	36.98	"	28.14	36.98	"	17.52	26.09
	TLM-TRJ-DISP	TLM $_{ND,L}$	"	36.32	→	→	"	30.23	35.73	"	30.23	35.73	"	24.50	25.73
		TRJ $_{ND,L}$ (3)	"	15.63	18.77	→	"	15.63	18.77	"	15.63	18.77	"	10.66	13.08
		DISP $_{L}$	"	72.29	78.17	→	"	63.92	78.17	"	61.50	78.17	"	47.25	55.43
	TLM-TRJ/DISP	TLM $_{ND,L}$	"	36.32	→	→	"	30.23	35.73	"	30.23	35.73	"	24.50	25.73
		TRJ $_{ND,L}$/DISP $_{L}$ (3)	"	87.92 NO	96.74 NO	→	"	77.52 NO	96.74 NO	"	77.13 NO	96.74 NO	"	57.91	63.95
Launch/ Function Hybrid (functional elements do not support launches)	TLM-TRJ-Launch (4)	TLM $_{D,NL}$	"	82.05	96.46	→	"	82.05	95.49	"	65.17	95.49	"	55.20	69.61
		TRJ $_{D,NL}$ (3)	"	26.35	36.98	→	"	26.35	36.98	"	26.35	36.98	"	13.66	24.29
	TLM-TRJ-DISP-LCH (4)	TLM $_{ND,NL}$	"	29.91	35.73	→	"	29.91	35.73	"	23.82	35.73	"	19.91	25.73
		TRJ $_{ND,NL}$ (3)	"	13.60	18.57	→	"	13.60	18.57	"	13.60	18.57	"	6.80	11.77
		DISP $_{NL}$	"	63.92	78.17	→	"	63.92	78.17	"	53.13	78.17	"	41.18	55.43
	TLM-TRJ/DISP-Launch (4)	TLM $_{ND,NL}$	"	29.91	35.73	→	"	29.91	35.73	"	23.82	35.73	"	19.91	25.73
		TRJ $_{ND,NL}$/DISP $_{L}$ (3)	"	77.52 NO	96.74 NO	→	"	77.52 NO	96.74 NO	"	66.73 NO	96.74 NO	"	47.98	67.20 NO
Mission/Display Hybrid	Standalone except DISP centralized	MISSION $_{ND,L}$ (5)	34.87 **	N.A.	N.A.	N.A.	SAME AS PRIME	N.A.	N.A.	SAME AS PRIME	N.A	N.A.	SAME AS PRIME	N.A.	N.A.
		DISP $_{L}$ (1)	N.A.	72.29	78.17	→	N.A.	63.92	78.17	N.A.	61.50	78.17	N.A.	47.25	55.43

* Key and notes on next page **26.42 for a non-launch case

TABLE B.4 - II

SIZING BUILDING BLOCKS
(Continued)

KEY: Subscript "D" - Display functions are included

" "ND" - Display functions are not included

" "L" - Launch contributions to the function may be included

" "NL" - Launch contributions to the function may not be included

XX.XX ⟶ - XX.XX applies to the entry where it appears and to all entry positions through which the arrow is drawn

XX.XX NO - Margin requirements for non-Real Time functions may not be satisfied by any Series 360 machine.

$\boxed{\text{YY.YY}}$ - May use a model 50 } Otherwise a model 75 is required

YY.YY - May use a model 65

NOTES: (Reference circled numbers in chart)

1 Same as the worst-case loading for the $DISP_L$ element in the pure functional configuration.

2 Assumed that the functional allocation scheme adopted for LIVE missions will apply to support of SIM's as well even when a mix of LIVE and SIM data in the same processing element is implied. Otherwise, software packages unique to SIM would be required.

3 TRJ loads assume two major burns constituting two simultaneous critical phases (or one such burn concurrent with launch). Fixing the number of simultaneous critical phases at 2, although considered a variable, was done to simplify the inter-relationships between variables.

4 Sizing for launch element does not appear. 360/75 assumed for such an element.

5 %CPU Time Used figures for MISSION elements in the Mission/Display Hybrid case slightly exceed the margin requirements assumed for design purposes. Margin requirements are violated, however, only when a launch is in progress and is being supported by the MISSION element. Because the loading figures conservatively assume that EM and LM vehicles are active during launch, means of decreasing the total load to meet the margin requirements are considered to exist.

TABLE B.4 - III

SUMMARY OF RTCC LOADING ESTIMATORS

All loading figures represent % CPU time used when the central processor (CPU) is a 360, Model 75.

Telemetry Loading Estimators (applicable to all mission phases unless otherwise indicated)

Loads on a per vehicle basis are as follows:

Vehicle	Input Processing Load	Display Processing Load	Total TLM Load/Vehicle
S-I or S-II	1.82%	2.53%	4.35%
S-IVB (incl. IU)[a]	2.77	3.54	6.31
CSM	4.18	8.26	12.44
LM[b]	3.91	6.06	9.97
EM	1.91	2.53	4.44

[a]Loading figures apply to launch phases. When in orbit phase, an S-IVB is considered as an EM for post-Apollo sizing purposes.

[b]Loading figures do not include ground support for a Launch Abort Computer (LAC).

In addition, 1.62% must be added to all TLM totals whenever loading is estimated for a vehicle combination involving at least one guidance computer (any time a S-IVB, CSM, or LM is included).

Trajectory Loading Estimators (for real-time portion of trajectory processing)

Loads on a per "target" basis are provided below as distinguished by vehicle phase where the distinction between powered flight and orbit phases is equated to the distinction between high-speed and low-speed tracking, respectively.

Vehicle Phase	Input Processing Load	Display Processing Load	Total TRJ Load/Target
Launch	8.83%	5.66%	14.49%
Powered Flight	4.97	5.66	10.63
Orbit	1.83	0.23	2.06

Display Request Loading

All loads other than for display request processing are included in the above. To account for this particular load, 0.97% must be added to the total TLM and TRJ loading for any element which processes display requests.

element would be required (in the worst case) to support the SR 500 Prime Model with two concurrent operations if a three-part functional system organization were adopted (TLM-TRJ-DISP).

Results are presented in 360/75 terms because the estimators themselves were developed using 360/75 data as a basis. Two types of information are required to convert numerical loading entries to a definition of which of three 360 Series machine models (50, 65, 75) may support that loading condition. These are:

1. Computing Speed Ratios

Such ratios are required to relate the % of a Model 75 used for a given set of processing tasks to the % of a Model 50 or 65 required to support the same complement of tasks. Ratios employed for purposes of this design effort are as follows:

$$\frac{\%\text{ of 65 Used}}{\%\text{ of 75 Used}} = 2; \qquad \frac{\%\text{ of 50 Used}}{\%\text{ of 75 Used}} = 5$$

These ratios are designed to conservatively estimate the capabilities of machines other than a 360/75. Derivation of these ratios involved a variety of data sources, most important of which were verbal discussions with IBM personnel, Auerbach report data on comparative execution times and documented IBM estimates such as those referenced in Appendix A.3.

2. Assumed Margin Requirements

Table B.4-II loading entries reflect only the real-time processing load as defined in Appendix A.3. For those computing elements performing only real-time tasks, table entries reflect the total load and no "margin" is required; i.e., entry values of up to 100% may be tolerated for such elements. "TLM" or "DISP" elements fall within this category. All other types of computing elements (TRJ, TRJ/DISP, and MISSION) are required to accomplish non-real-time processing tasks. While being executed, non-real-time tasks generally demand 100% of any CPU time not required by real-time functions; the difference between 100% and the %CPU time used for real-time functions, therefore, constitutes a "margin" whose magnitude determines the amount of time available to complete non-real-time tasks.

It has been assumed that certain minimum margins must be preserved as follows:

- The equivalent of 20% of a 360/75 if the computing element supports only a single mission (applicable to any MISSION element).
- The equivalent of 35% of a 360/75 if the element provides multiple-mission support (applicable to any TRJ or TRJ/DISP elements).

The relationships between %CPU time used table entries, computing speed ratios, and assumed margin requirements for non-real-time functions permit formulation of the following summary table:

Element	May Use Model 75 if %75 Used ≤	May Use Model 65 if %75 Used ≤	May Use Model 50 if %75 Used ≤
TLM or DISP	100	50	20
MISSION	80	30	Never*
TRJ or TRJ/DISP	65	15	Never*

*Does not preclude use of a Model 50 in some kind of limited support capacity.

This summarization has been employed to specify the required machine models in Table B.4-II, thereby completing the process of developing the Step 3 design "building blocks." Note that the two alternatives involving a TRJ/DISP element violate the 35% of a 360/75 margin requirement for non-real-time processing for all cases except when supporting Interim Model 3. Even in the Interim Model 3 support cases, however, use of a TRJ/DISP element results in a very uneven distribution of real-time loads between elements. These two factors-inadequate support for non-real-time processing and unfavorable loading distributions - have caused the two TRJ/DISP alternatives to be eliminated from further consideration. As a result and as indicated by the structure of Table B.4-I, complete design results need be developed for only the six remaining system organization alternatives.

Viewing Table B.4-II on a row by row basis by scanning from left to right, one observes several instances in which the machine model associated with a single entry designates a smaller machine than required to support any other load in that same row. In particular, these instances consistently occur when supporting Interim Model 3 with only two concurrent operations. For example, the DISP element in a TLM-TRJ-DISP is sized as a 360/75 in all cases except when supporting Interim Model 3 with two concurrent operations; in this case, a Model 65 is adequate. Because it is considered undesirable to select machine models which have such limited applicability (they may prove inadequate if only slight increases in vehicle support requirements occur), all design results have been generating by assigning the next larger machine model in each such unique instance. In terms of the previous example, therefore, the DISP element in a TLM-TRJ-DISP configuration would always be sized as a 360/75.

Based on the above, Table B.4-II may be reduced to the statement that a 360/75 is required in all but a few cases for which a 360/65 is adequate. In particular, a 360/65 may be employed -

- For all models and schedules regardless of the number of concurrent operations;
  - As the TLM element in a TLM-TRJ-DISP or in a TLM-TRJ-DISP-Launch configuration.
  - As the mission element in a Mission/Display Hybrid configuration.
- For any model or schedule and two concurrent operations;
  - As the TRJ element in a TLM-TRJ-DISP-Launch configuration

- For Interim Model 3 and either two or three concurrent operations;

  - As the TRJ element in a TLM-TRJ-DISP configuration.

- For Interim Model 3 with three concurrent operations;

  - As the TRJ element in a TLM-TRJ-DISP-Launch configuration.

All of the above supports the conversion of a number of machines (product of Step 2 of design process) into a specific complement of Series 360 machines. The conversion process must account for the fact that backup for a particular machine model must be provided in the form of the same machine model. Situations arise, therefore, in which taking advantage of the ability to use a 360/65 (rather than a 360/75) would cause an inefficient mix of machine types from a backup viewpoint. In particular, an increase in the number of machines required to provide adequate backup may more than offset the cost advantages associated with use of a 360/65 rather than a 360/75. In such cases, results reflect use of a 360/75 for certain elements regardless of the loading requirement. As a result, a detailed study of Table B.4-I will uncover a small number of RTCC configurations whose mix of machine models does not, on the surface, appear consistent with the above summarization of machine model "building blocks."

Although not discussed previously, results in Table B.4-I indicate size of main memory as well as central processor model number. This additional definition of the direct support configuration has been achieved by making the relatively crude judgment that "J" memories are required by MISSION or launch elements while, because of the lesser program size associated with functionally-oriented machines, "I" memories are adequate for TLM, TRJ, or DISP elements. In addition, the removal of display processing programs from MISSION element storage in the Mission/Function Hybrid case led to assignment of an "I" memory to the mission element in this case. The memory size distinctions, however crude, are considered necessary if cost data is to reflect the potentially significant storage advantages of functional orientation.

Determination of the Total Machine Complement (Reference Step 4 of design process)

Completion of previous design steps produces an RTCC configuration designed to satisfy direct mission support requirements, but not necessarily adequate from a computer hour viewpoint. This step involves estimating total computer hour requirements in terms of 360/75 time, calculating the portion of this total which may be satisfied by machines already "bought" as part of the direct mission support configuration and selecting additional machines to satisfy any remaining computer hour demands. As such, this step produces the "Total Machine Complement" entries in Table B.4-I.

Given the summary curves in Appendix A.4 which show computer hour requirements as a function of mission density, estimation of total requirements in terms of 360/75 hours is a relatively straightforward process. (The GSSC component of these curves has, of course, been subtracted.) Specifically, the total requirements may be calculated as the sum of the number of hours represented by the appropriate "density point" on the Appendix A.4 curves and the number of computer hours for LIVE mission support as tabulated in Appendix B.3, Table B.3-IV, and as tailored to the nature of the organizational scheme being considered. Initial results achieved in this manner are presented in Table B.4-IV, with the required number of 360/75 machines calculated assuming 525 hours/month of productive time per machine.

In the interests of conservatism, some margin of safety has been introduced by the manner of using Appendix A.4 curves during the process of generating total requirements. Appendix A.4 computer hour estimators are developed in terms of mission density rather than flight density. Although post-Apollo missions are often of a multiple-flight character, a single post-Apollo flight has been equated to a Gemini or early Apollo mission for purposes of computer hour estimation. (Conservatism is, of course, not the only impetus behind this approach; when compared to Gemini or early Apollo flights, post-Apollo flights generally are characterized by more vehicles and perhaps by a greater degree of mission-by-mission software changes due to the presence of EM's.) Secondly, computer hour totals have been derived using the Appendix A.4 curves which do not take advantage of multi-jobbing potential within the RTCC.

The computer hour totals in Table B.4-IV are presented in terms of "equivalent 360/75" requirements. To permit consideration of Series 360 machines other than the Model 75, factors must be established which equate hours on a Model 65 or Model 50 to equivalent 360/75 hours for various job categories. Appendix A.4 introduces the distinction between "job shop time" and "block time." For the job shop component of the total computer hour requirements, the computing speed ratios previously developed provide the necessary conversion factors; the amount of computer time used to accomplish a "job shop" task is purely a function of execution speed. Consideration of the block time component is more complex; although the duration of a block time task is independent of the execution speed, the loading associated with certain block time tasks may eliminate machines smaller than a 360/75 from further consideration. This issue has been approached first of all by assuming that a Model 75 and a Model 65 are indistinguishable from a block time viewpoint as long as Model 65 machines are included in the direct support configuration. Secondly, it has been concluded that the portion of block time which may be safely satisfied by a Model 50 is limited and that this portion must be specifically identified for each category of computer hour demand. In particular, the approach has been to divide each category of computer hour demand into three components based on assumptions regarding the makeup of each such category. The three componenets are:

- Job shop time
- Block time which requires the same machine models as associated with operational processing (Model 65 is applicable only if part of direct support configuration)

TABLE B.4 - IV

TOTAL COMPUTER HOUR REQUIREMENTS IN HOURS/MONTH[b]
FOR ALL REQUIREMENTS CASES AND SYSTEM ORGANIZATIONS

CASES OF INTEREST[a]	SYSTEM ORGANIZATIONS				
Description	Assoc. Density flts/yr.	Standalone	With 2 Funct. Elements	With 3 Funct. Elements	Mission Display
ML-65-3, Peak Density (cases 1 & 2, Table B.3-IV)	13.0	3942/7.5	4342/8.3	4799/9.1	4399/8.4
ML-65-3, Avg. Density (cases 3 & 4, Table B.3-IV)	11.4	3523/6.7	3876/7.4	4278/8.1	3925/7.5
M(P)-2A, Peak Density (cases 5 & 6, Table B.3-IV)	10.0	3339/6.4	3822/7.3	4353/8.3	3870/7.4
M(P)-2A, Avg. Density (cases 7 & 8, Table B.3-IV)	8.4	2906/5.5	3325/6.3	3786/7.2	3367/6.4
SR 500 Prime Model (case 9, Table B.3-IV)	8.0	2758/5.3	2842/5.4	3106/5.9	3022/5.8
SR 500 Interim Model 3 (Case 10, Table B.3 - IV)	8.0	2758/5.3	3082/5.9	3466/6.6	3142/6.0

NOTES:

[a]As indicated, only six different computer hour totals are required to cover the ten cases in Table B.3-IV.

[b]Table entries in the form "X/Y" should be interpreted as "X" total hours per month requiring "Y" 360/75's or their computer hour equivalent.

- Block time for which a Model 50 may be employed

Table B.4-V presents the results of applying the above approach. Note the distinction between constant demands and demands which are sensitive to flight density. Based on this distinction and excluding the requirements associated with support of actual missions, Table B.4-V may be reduced to the following:

Type of Demand	Assoc. Hours	DEMAND COMPONENTS: Job Shop	Block Time Requiring "Oper" Mach.	Block Time Supportable by Model 50
Constant	530 hrs/mo.	81.14%; 430 hrs	9.43%; 50 hrs.	9.43%; 50 hrs.
Sensitive to Flight Density	223 hrs/mo/ mission	16.83%; 38 hrs.	65.51%; 146 hrs.	17.66%; 39 hrs.

Based on the preceding data and analysis, definition of the total machine complement has been achieved using the following sequential steps:

a. Calculate the difference between the total number of computer hours provided by the direct support configuration and the number of computer hours per month devoted to support of actual missions. Result: the number of hours within the "direct support configuration" which are available to support other computer hour demands.

b. Determine, using the above summary of conversion factors and the appropriate computing speed ratios, which of the non-direct support computer hour demands may best be satisfied by time remaining within the direct support configuration. Subtract the result from the total of non-direct support computer hour requirements. Result: the number of non-direct support computer hours to be provided "outside" of the direct support configuration.

c. If result of "b" is equal to or less than zero, the direct support configuration without additions will satisfy all computer hour demands. If the result is greater than zero, determine the additional machine complement which most economically satisfies the outstanding requirements. Result: the total machine complement. (See columns (8), (11), (14), (17), (20) and (23) of Table B.4-I).

Note that a determination of the most economical means of satisfying any outstanding computer hour demands requires use of the conversion factors and computing speed ratios as in the preceding step as well as the cost per configuration figures developed in the subsequent section. Cost tradeoffs exist, for example, in determining whether additional equivalent 360/75 computer hours may most cheaply be satisfied by converting 360/65's within a configuration to 360/75's or by leasing an additional machine such as a Model 50. For a specific illustration, refer to the total Mission/Display Hybrid machine complement (column 23) required to satisfy the combination of requirements represented by row 33. A detailed consideration of computer hour requirement components showed

TABLE B.4 - V

BREAKDOWN OF COMPUTER HOUR DEMANDS IN SUPPORT OF IDENTIFYING APPLICABLE MACHINE MODELS

COMPUTER HOUR DEMAND CATEGORIES[a]	Hrs/Mo or Hrs/Mo/Miss[b]	DEMAND COMPONENTS		
		Job Shop	Block Time Requiring "Oper" Machines	Block Time Supportable by Model 50
Mission Program Development	113/miss	25%; 28.25hrs	47%; 53.11 hrs	28%; 31.64 hrs.
Dynamic/Script	21/miss	25%; 5.25 hrs	60%; 12.60 hrs	15%; 3.15 hrs.
ORACT	27/miss	15%; 4.05hrs	68%; 18.36 hrs	17%; 4.59 hrs.
Operational Support (Non-LIVE)	62/miss	-	100%; 62 hrs	-
Direct LIVE Support	See Table B.3-IV	-	100%; See B.3-IV	-
RTOS Development	200	50%; 100 hrs	25%; 50 hrs.	25%; 50 hrs.
System Analysis & Miscellaneous	330	100%; 330 hrs	-	-

NOTES:

[a]Demand categories other than "Direct LIVE Support" correspond to those employed in the development of Appendix A.4 computer hour estimators.

[b]All figures appearing in this column are provided on a per month basis with the per mission indication distinguishing between constant demands and those which are a function of flight density.

that provision of adequate 360/75 job shop time (or its equivalent) required either the addition of a 360/75 or the addition of a 360/50 combined with conversion of the 5 65's in the direct support configuration to Model 75's. The latter is less costly; therefore, the result - 7 360/75's, 1 360/50 - despite the appearance of Model 65's in the direct support configuration. Because of such cost tradeoffs, cases such as the one discussed exist in which the direct support machine complement is <u>not</u> a specific subset of the total machine complement.

Calculation of Configuration Costs
(Reference Step 5 of design process)

Because the selection between Augmentation II alternatives is considered to be a task of comparative evaluation, cost differences are of primary interest. The concept of cost "building blocks" was introduced in Appendix B.1 with such building blocks being defined as the dollars per month required to lease a representative configuration of Series 360 equipments. Inaccuracies, of course, are inherent to the building block approach because cost differences associated with detailed configuration characteristics are not reflected. It has been concluded, however, that sufficient accuracy is maintained by the building block approach and that the ability to deal with only a small set of figures is a necessity rather than a convenience when costing the large number of machine complements identified in Table B.4-I.

Step 4 design results dictate that cost figures be developed for representative configurations of the following Series 360 machines: 75J, 75I, 65I, 50I. Costs developed for 75 and 65 configurations reflect only the main frame model and main memory size as distinguishing cost features; costs for peripherals and interface equipments are considered to be constant. Relative cost differences, therefore, may be easily identified. Model 50 costing assumes provision of essentially the same equipment complement as characterizing the 50's which are presently employed with the addition of real-time interface capabilities (2701 and associated interface adapter, 2902 and associated adapters, additional computer channels). Real-time interface capabilities have been added to facilitate block time usage and to support potential assignment to an operational processing role (limited support, experiment data reduction, etc.). The resulting cost figures are tabulated below.

Table B.4 - VI
COST "BUILDING BLOCKS"

Configuration	Cost/Month	Basis
75J	110K	Costs per Equipment Development Plan Volume of IBM's System Eng. Series, NAS9-996.
75I	90K	75J costs minus reduction associated with decreased memory size.
65I	81K	75I cost minus reduction associated with "smaller" main frame.
50I	39K	Costs for present 50's (same document source as for 75) plus approximately 6K for real-time interface capabilities.

Comments supporting a meaningful interpretation of the above figures are as follows:

. Certain cost items - adjustment for credit, charge for "extra" hours, etc. - are not included in the above because of their omission from the IBM figures used as a base. These account for any discrepancies between the above and actual contract costs borne by NASA. Their omission is not considered to violate the "ball park" costing objective.

. As indicated, the above costs are applicable to dedicated configurations. Because the implementation of an integrated system (in the IBM sense) is a possibility for the post-Apollo area, a quick look was taken at the total cost impact of adopting such a scheme. Based on the integrated system configuration appearing in the IBM document referenced above, a comparison was made between dedicated costs for a 75J configuration (as above) and a "cost per integrated 75J" consisting of the sum of the per 75J costs for all dedicated equipments and the cost for all shared equipments as prorated over the total number of 75J elements (five in this case). Result: differences were too small to be of concern for this gross look at total costs. Because these differences are associated only with peripherals and interface equipment, the same result applies for any 65 or 75 configuration; relative differences between main frame and memory costs are not sensitive to the dedicated vs. integrated distinction. (This admittedly preliminary result suggests that, because equipments which are always dedicated constitute such a large percentage of system cost, one should carefully investigate the economies versus the complexities of an integrated RTCC system approach.)

In summary, the Table B.4-VI cost figures are considered adequate to support comparative evaluation despite the fact that they are neither fully complete nor fully accurate.

Further observation of Table B.4-VI leads to some interesting generalizations. Little savings are incurred by employing a Model 65 rather than a Model 75 as long as memory size is a constant. (Model 75 provides more executions per dollar.) Significant savings, conversely, are achieved by reducing the amount of main memory required. Furthermore, significant savings are always incurred by "replacing" a 65 or 75 configuration with a Model 50 - a not unexpected result. These generalizations are made at this point only to identify relationships which significantly influence the Table B.4-I design results before these relationships are lost in the cost totals.

SPECIFIC EXAMPLE

An example is provided to more clearly relate the design development steps described above to the results expressed in Table B.4-I, Matrix of Design Results. In particular, Figure B.4-1 depicts RTCC support of a particular combination of requirements for each of two system organization alternatives. The combination of requirements to be supported, viewed as a design point within the spectrum of requirements as described in the figure itself, corresponds to row 66 of Table B.4-I. Design results related to this particular design point are illustrated for both a standalone and a TLM-TRJ RTCC system organization and are expressed in columns 7 - 9 and 10 - 12, respectively (reference row 66 in each case). Figure B.4-1 distinguishes between the direct support configuration and the additions thereto needed to satisfy computer hour demands.

For the standalone configuration, mission computers 1 through 4 (M1 - M4) of the direct support configuration are associated with the requirement to support four concurrent operations while two backup machines provide adequate redundancy in terms of the "redundancy ratio" previously defined. Vehicle support requirements and associated loading dictate sizing of the standalone machines as 360/75's while program package size considerations indicate the need for "J" memories. Two machines, a 75J and a 50I, are added in support of computer hour requirements which can not be accommodated within the direct support configuration.

For the TLM-TRJ configuration, the direct support configuration consists of two multi-mission functional elements and a single backup machine providing redundancy. Vehicle loading dictates sizing as 360/75's with "I" memories estimated to provide adequate program and table storage. Significant computer hour additions are required to support the flight density and duration characteristics of the design point of interest.

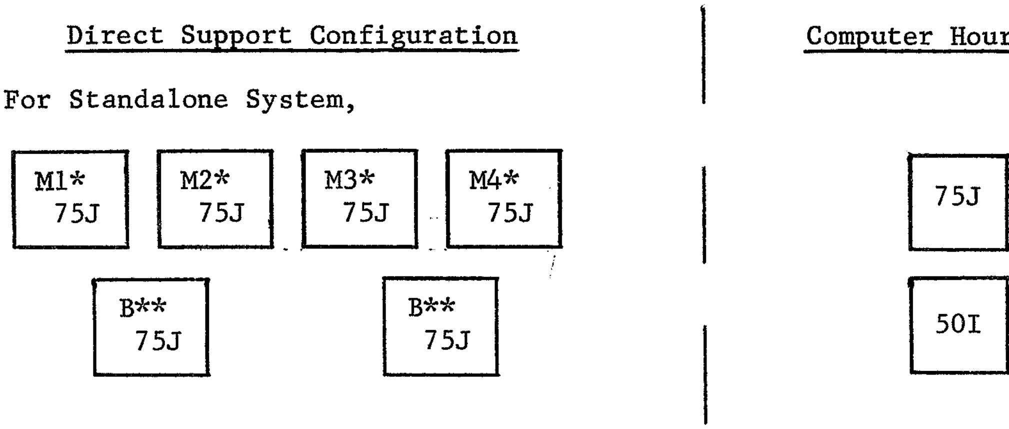
This particular example clearly indicates the importance of computer hour requirements when considering RTCC system design. The direct support configuration did not provide adequate computer hours in either of the two system organization cases. Furthermore, computer hour requirements tend to override the significant cost advantages of a TLM-TRJ configuration over a standalone configuration from a direct support viewpoint.

DESIGN POINT: ML-65-3, Peak Density Year

Four concurrent operations, two simultaneous critical phases, startup backup for critical phases

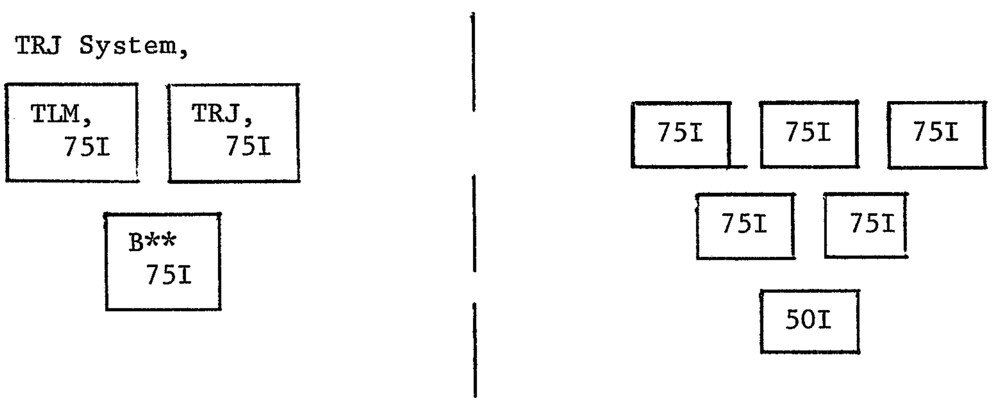
Direct Support Configuration | Computer Hour Additions

For Standalone System,



Total Machine Complement = 7 75J's, 1 50I;
$809/month, hardware rental.

For TLM - TRJ System,



Total Machine Complement = 8 75I's, 1 50I;
$759K/month, hardware rental

* Mission oriented machines to support four concurrent operations
** Backup machines in the startup/startover sense

Figure B.4-1

EXAMPLE OF DESIGN RESULTS

APPENDIX B.5

DISCUSSION AND SUMMARY OF DESIGN RESULTS

INTRODUCTION

The design effort described in the preceding appendix material may be viewed as culminating in Table B.4-I, the matrix of design results. Despite its merits as a convenient format for recording design results, Table B.4-I does not readily support an analysis or identification of important relationships between costs and requirements for various RTCC system organizations. The primary purpose of this appendix, therefore, is first to summarize the matrix results in a form which facilitates analysis and then to perform such an analysis with the objective of making both general and specific observations regarding the selection of an RTCC design approach. Auxiliary Computing Room (ACR) and Ground Simulation Support Computer (GSSC) considerations are specifically introduced. Finally, a summary of conclusions and recommendations is provided.

Conclusions and recommendations developed in subsequent sections of this appendix are based primarily, if not exclusively, on cost considerations. To the extent that a fuller consideration of factors other than cost is judged necessary or desirable, the conclusions and recommendations are appropriately qualified. Note, however, that comparative costs in themselves may constitute a sufficient basis for selecting a design approach if reasonably clear-cut evaluation based on other criteria is precluded by the level of design detail or by an inability to reliably predict the impact, in terms other than cost, of pursuing various alternatives.

FACTORS INFLUENCING THE MATRIX RESULTS

Appendix B.4 described in detail the step-by-step development of the matrix of design results represented by Table B.4-I. Regarding this development, summary comments are compiled at this point in the interest of clearly identifying those factors (or intermediate design results in some cases) which most significantly influence the relationships between cost and requirements for the various RTCC organization alternatives. Specific comments are as follows:

Related to worst-case vehicle loading (% CPU Time Used)

> The two RTCC organizations involving a "TRJ/DISP" processing element provide an inadequate processing margin for non-real-time mission support functions. They are, therefore, considered unacceptable.
>
> All mission support elements are sized as 360/75's or 360/65's based on loading estimates for the worst-case vehicle support requirements. As a corollary, note that the range of vehicle support requirements represented by the requirements spectrum demands a reasonably narrow range of machine processing speeds.

The machine models required to support the two reference planning schedules - M(P)-2A and ML-65-3 - are not sensitive to whether or not slippage in these schedules is assumed. As a result, distinctions between different requirements combinations based on schedule slippage do not cause corresponding differences in the required RTCC configuration.

Related to computer hour sizing

Computer hour requirements are generally "overriding" in the sense that, for many points in the requirements spectrum, these requirements result in additions to the direct support configuration; i.e., the direct support configuration does not provide sufficient computer hours for mission program development, RTOS maintenance, etc.

A single 360/50 may generally be economically included in the RTCC configuration to support "block time" computer hour requirements which are insensitive to machine processing speed.

Related to costing

Main frame cost differences between a 360/75 and a 360/65 ($9K/mo.) are less significant than the cost difference between and "I" and a "J" memory ($20K/mo.). Considering this in light of the above statement on vehicle loading results, one concludes that vehicle loading differences exert a minor influence on comparative configuration costs while system organization differences which cause different main memory requirements exert a significant influence on comparative configuration costs.

These comments are intended to assist the reader in understanding the summary data which follows.

CONVERSION OF MATRIX RESULTS TO A GRAPHICAL SUMMARY

An analysis of design results may be undertaken with a variety of related objectives such as the identification of significant trends and general cost relationships between various organization alternatives, the comparative cost evaluation of alternatives designed to support the same design point in the requirements spectrum, the investigation of the sensitivity of configuration costs to changes in requirements for a particular organization alternative, and the detection of requirements "thresholds" where changes in the system organization approach are suggested by cost considerations. Conversion of the matrix information to a form which lends itself to such analysis is the main subject of this section.

Structure of Graphical Summary

Because cost is the only common denominator for all design results, a cost vs. requirements graphical summary is used to summarize results. Figure B.5-1 represents such a summary. In particular, cost as a function of

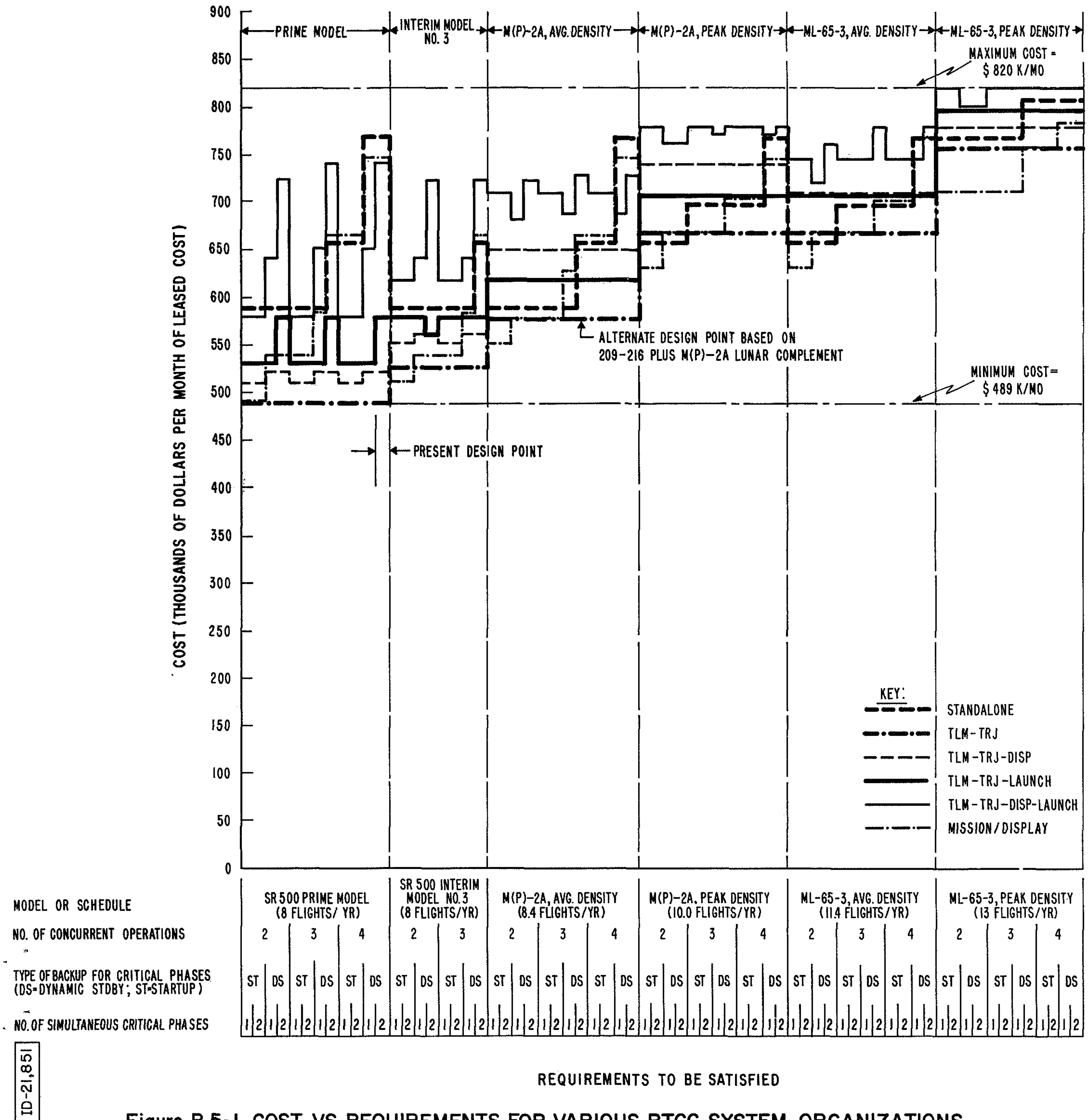


Figure B.5-1. COST VS REQUIREMENTS FOR VARIOUS RTCC SYSTEM ORGANIZATIONS requirements is graphed for each of six RTCC organization alternatives, each alternative represented by a specially-coded or keyed line.

As indicated, cost figures reflect leased hardware costs on a monthly basis. Because costs were developed in terms of the basic monthly rental only, actual contract costs incurred would be greater than those appearing in Figure B.5-1. This limitation, however, is not considered to preclude use of the cost data for comparative evaluation. Despite the significance of software and related manpower costs, omission of these costs is not considered to preclude meaningful comparative evaluation because clear differences between the various organization alternatives in terms of such cost factors are neither apparent nor "quantifiable" at this point in time.

Points along the "Requirements" axis represent the set of design points or requirements combinations which constitute the requirements spectrum. Because each design point is discrete, plots of cost vs. requirements for various system organizations appear as step functions rather than as continuous curves. Each design point is identified either directly or indirectly in terms of the associated values for each of the six requirements variables delineated in Appendix B.1 and implied (or stated) by the column headings in the matrix of design results, Table B.4-I. In particular, each design point is associated with a unique row in Table B.4-I. Six (6) major portions of the "Requirements" axis are distinguished by the model or schedule to be supported and by the distinction between average and peak flight density in the case of the schedules. The model or schedule to be supported determines values for three of the six original requirements variables; flight density, the number of computer hours per month for support of actual missions, and the vehicles to be supported. Each of the other three requirements variables appears as an individual descriptor of each design point with the appropriate value stated explicitly for each point on the "Requirements" axis.

Note that ten (10) rather than six (6) model or schedule groupings would be expected based on Table B.3-IV, Appendix B.3. Only six cases appear in the summary because the original distinction based on the lack or presence of slippage in the reference planning schedules does not affect configuration costs and, therefore, is not of interest. Therefore, design results related to support of the reference planning schedules reflect configurations which may support any increased vehicle loading caused by schedule slippage. Note also that 68 rather than 115 distinct design points, the original total of requirements combinations, constitute the requirements spectrum depicted in Figure B.5-1. The fact that the need disappeared to distinguish between schedule cases with and without slippage (see above discussion) resulted in the deletion of 32 of the original 115 design points. An additional 15 design points were eliminated from Figure B.5-1 by the decision that the 15 "special cases" corresponding to rows 51 through 65 of the design results matrix, Table B.4-I, do not warrant inclusion in the cost vs. requirements summary.

Primary ordering of design points along the "Requirements" axis is determined by the model or schedule to be supported. The "Requirements" axis, in terms of the models or schedules to be supported, is specifically constructed such that flight density generally increases from left to right. This particular ordering is related to the identification of general cost trends as discussed in subsequent paragraphs. Ordering of design points at a more detailed level is controlled by the basically cyclic repetition of values for the remaining three requirements which define a design point; the number of concurrent operations ranges between two and four, the type of backup for critical phases alternates between dynamic standby and startup, and the number of simultaneous critical phases alternates between one and two. The "ordering" aspects of defining design points along the "Requirements" axis are emphasized because an understanding of these is critical to an understanding of the behavior of cost as a function of requirements for the various organization alternatives.

Figure B.5-1 is basic to much of the subsequent discussion and is referenced accordingly. The two design points specifically labelled in Figure B.5-1, in particular, are the subject of material which follows.

Cost vs. Requirements Behavior: Examples

The characteristics of a particular organization and of the ordering of design points along the "Requirements" axis must be jointly considered in order to understand the behavior of cost as a function of requirements. Consider as examples the cost vs. requirements graphs for each of three (3) organization alternatives as represented by Figures B.5-2 through B.5-4. Such individual graphs may be more easily interpreted than the multi-curve graph presented in Figure B.5-1.

Figure B.5-2 depicts cost vs. requirements for a standalone system. As would be expected in light of the characteristics of a standalone system, the number of concurrent operations and the two requirements variables associated with critical phase support exert a significant influence on system cost. In particular, observe that cost fluctuations occur within portions of the requirements spectrum associated with the same model or schedule to be supported. Note also, however, that cost exhibits a general upward trend with increasing density and that, as increasing density results in increasing computer hour requirements, computer hour requirements become more and more influential. This is evidenced by the fact that cost fluctuations due to other requirements diminish in magnitude.

Figure B.5-3, representing cost vs. requirements for the two-part functional split between telemetry and trajectory, illustrates a different behavior pattern than that associated with the standalone system. In this case, computer hour requirements are always "overriding" in the sense that such requirements always dictate additions to the direct support configuration and, therefore, determine total system cost. As a result, cost increases with flight density (and/or total computer hour requirements including mission support hours) as a simple step function. The same cost level applies to both M(P)-2A, peak density (10.0) and ML-65-3, average density (11.4), because computer hour increases caused by increased density are effectively "cancelled out" by computer hour decreases for direct mission support. Direct support computer hour requirements are less for ML-65-3 than for M(P)-2A because of the longer mission durations associated with the latter schedule. (Refer back to Figure B.5-1 for this same portion of the requirements spectrum. Note that, for the TLM-TRJ-DISP and TLM-TRJ-DISP-LAUNCH configurations, the decrease in direct support computer hours exceeds the increase due to density, thereby resulting in a temporary reversal of the upward trend of cost with density.)

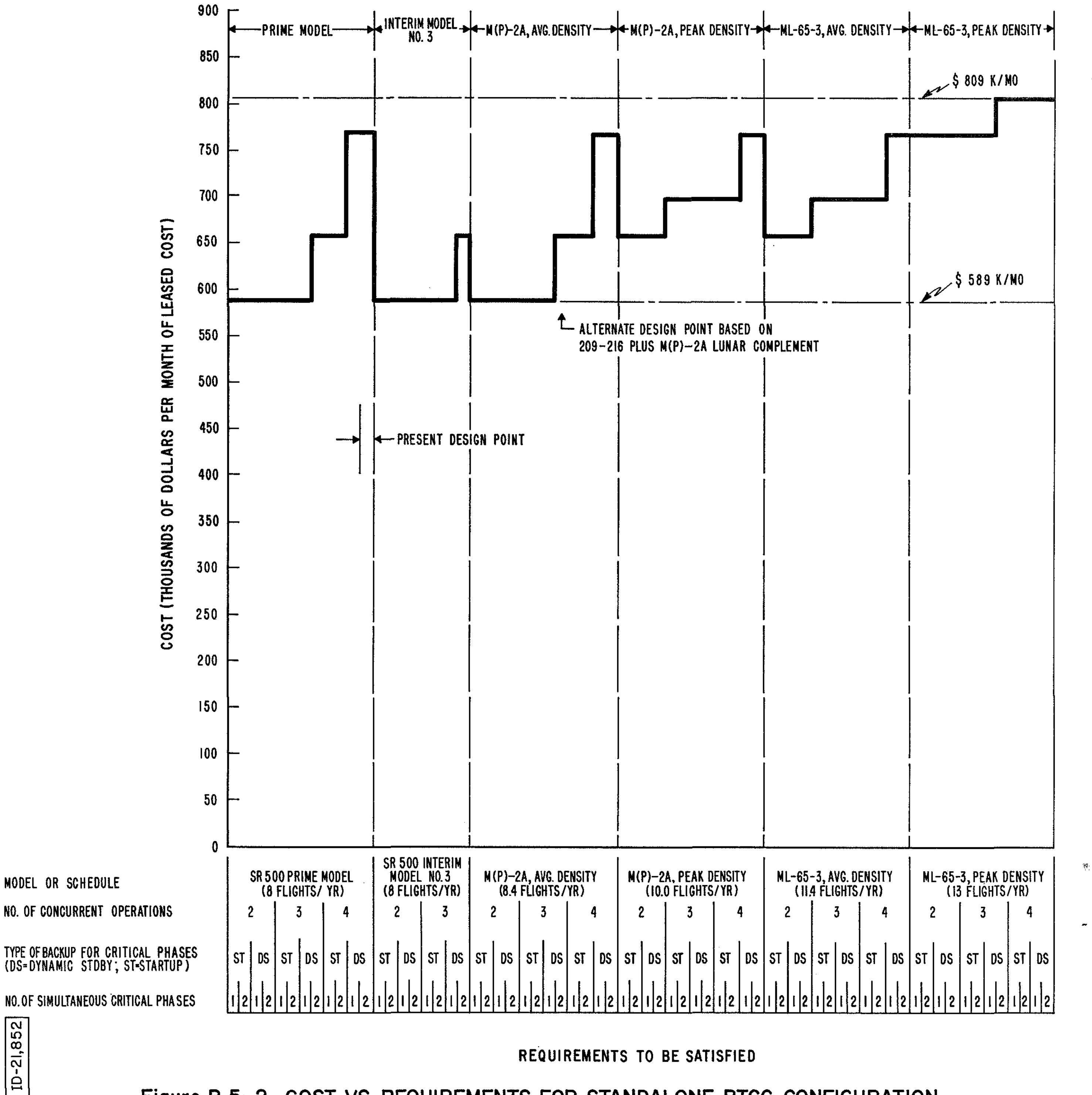


Figure B.5-2. COST VS REQUIREMENTS FOR STANDALONE RTCC CONFIGURATION

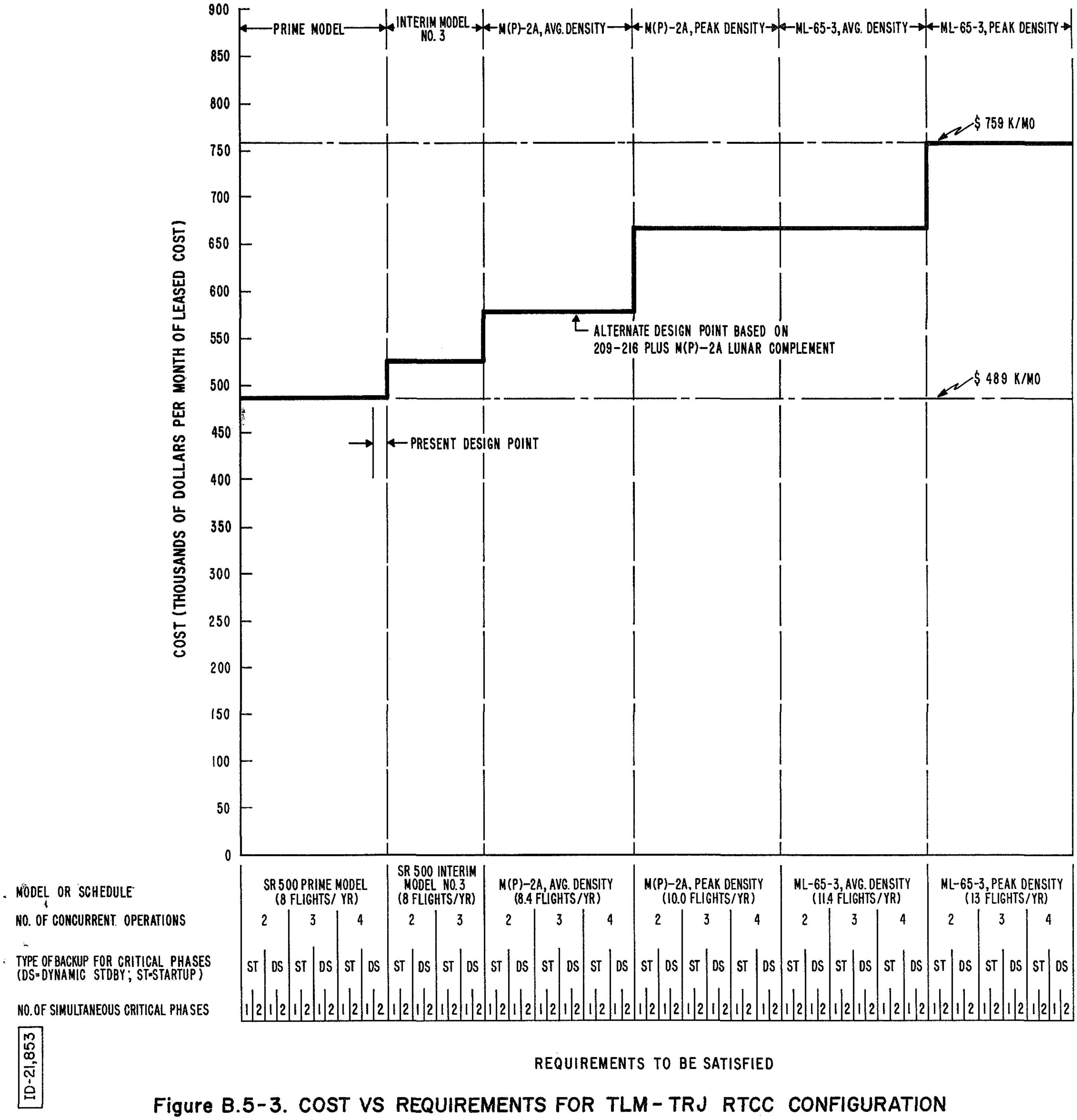


Figure B.5-3. COST VS REQUIREMENTS FOR TLM-TRJ RTCC CONFIGURATION

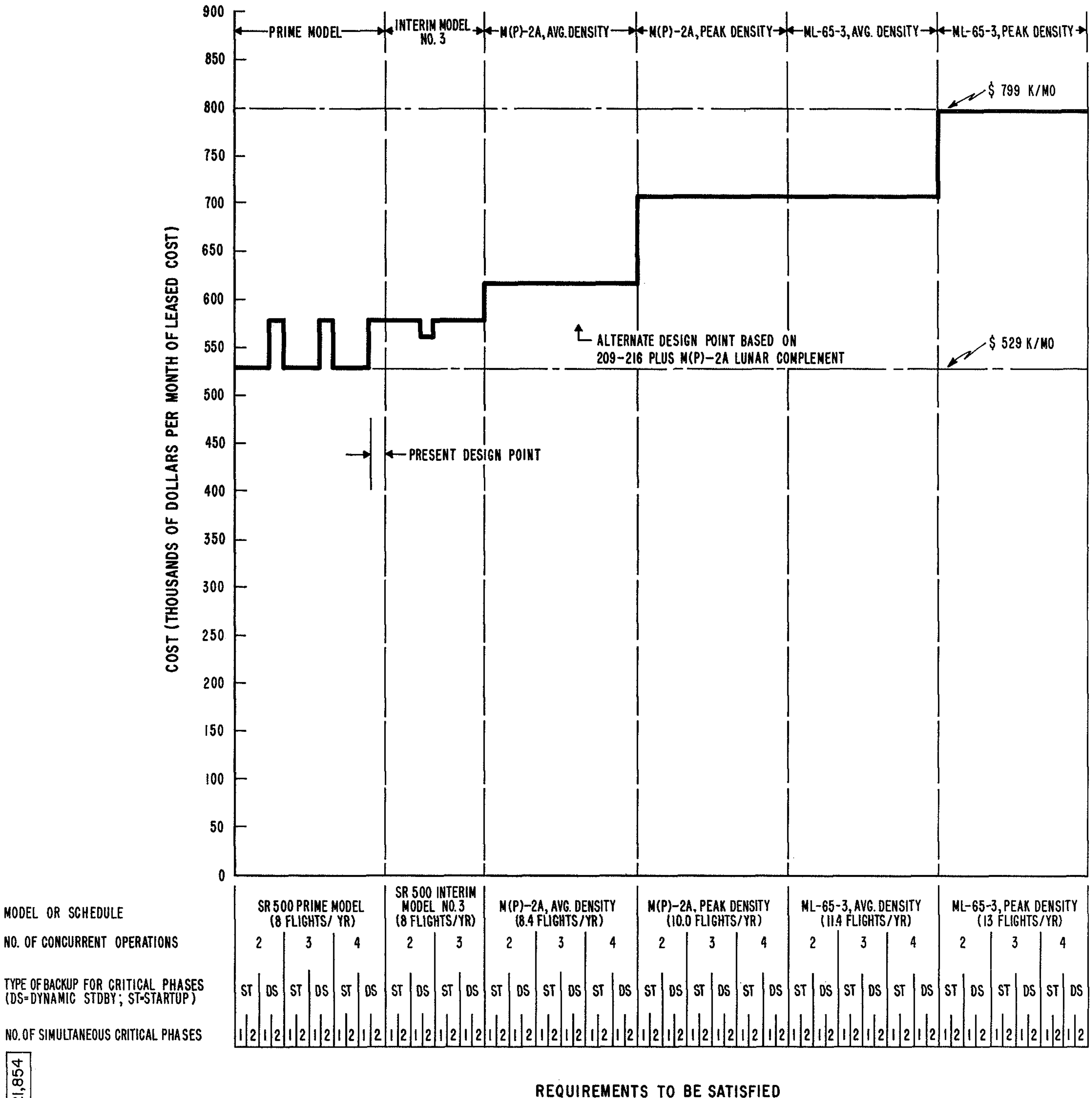


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Figure B.5-4. COST VS REQUIREMENTS FOR TLM-TRJ-LAUNCH RTCC CONFIGURATION

Figure B.5-4, applicable to the TLM-TRJ-LAUNCH configuration, evidences a combination of the cost vs. requirements behavior characterizing the two previous examples. Because mission-oriented support is provided for the launch phase, cost is sensitive to requirements other than the model or schedule to be supported (as in the case of the standalone system). This sensitivity exists, however, only at the lower end of the flight density range. As density or direct support computer hour requirements increase only slightly, computer hours dictate cost in the same manner as described above for the TLM-TRJ configuration. Note the unexpected decrease in cost for a single design point associated with support of SR 500 Interim Model #3. Although vehicle support requirements for Interim Model #3 permit use of a Model 65 for certain functional elements, costs do not always reflect use of the smaller machine. Only at the particular design point in question is the mix of 360/75 and 360/65 machines economical from a total machine complement viewpoint. The use of Model 65's in this unique case, therefore, causes the unexpected cost fluctuation. (Similar reasoning explains unexpected cost fluctuations in the TLM-TRJ-DISP-LAUNCH case.)

As examination of cost vs. requirements behavior for particular organization alternatives exposes their merits in terms of being relatively insensitive to changes in requirements, a desirable attribute. More specifically, constant costs throughout an appreciable portion of the requirements spectrum favor any alternative from a sensitivity viewpoint. This is particularly important when a specific design point may not be confidently identified.

GENERAL OBSERVATIONS

Certain general observations are supported by reducing Figure B.5-1 to only the envelope which bounds the costs vs. requirements curves for the six organization alternatives of interest. Figure B.5-5 is the result of such a reduction. Note that the straight line drawn roughly through the center of the cost envelope is included only to emphasize the general upward trend of cost with requirements; a truly linear relationship is not implied. This statement and earlier statements imply the most significant single general observation: computer hour requirements, as derived primarily from flight density, are generally the most significant single factor influencing system cost. This point has actually been made previously in various forms; it is reiterated here only for emphasis. A significant corollary of this observation has also been suggested by earlier discussion; the differences between minimum and maximum costs for given design points generally decreases as density increases. This occurs because computer hour requirements become more and more overriding and thereby exert an equalizing influence on costs for various alternatives.

Of interest at this point is an apparent contradiction to the observations made above. Although the same flight density applies to both of the SR 500 models considered, support costs are different for functionally-oriented configurations and, in particular, support of the Prime Model is <u>less</u> costly. An analysis of this seeming inconsistency uncovers the fact that direct support computer hour requirements for functional machines are less for the Prime Model than for Interim Model #3. More importantly, however, this fact indicates that the worst-case vehicle loading characteristics of the Prime Model result in a degree of overlap between flights which

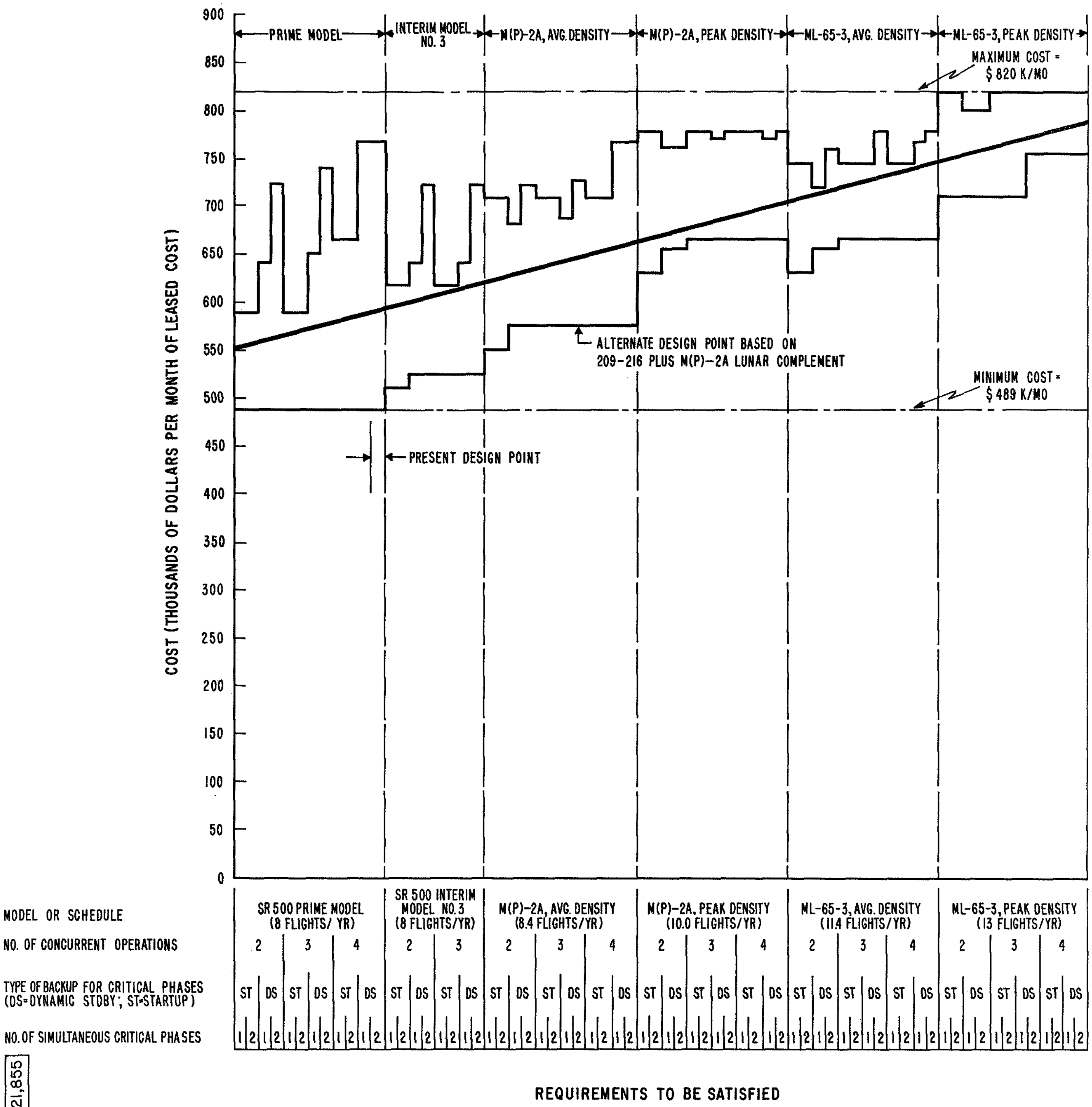

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Figure B.5-5 COST VS REQUIREMENTS ENVELOPE THROUGHOUT REQUIREMENTS SPECTRUM

creates conservative, if not unrealistic, direct support computer hour requirements. In particular, the increased degree of overlap permits functionally-oriented configurations to take advantage of their multi-mission support capability. It is not clear, however, that such overlap would occur for a flight schedule with a density of only eight (8) flights per year.

To provide a feel for whether or not variations in cost with requirements are truly significant, it is observed that -

> Approximately $4M/year represents the difference between the minimum and maximum cost lines appearing in Figure B.5-5.
>
> A range of six (6) to ten (10) processing elements is associated with the support of the requirements spectrum.

Cost Relationships Throughout the Requirements Spectrum

Before considering comparative costs to support specific design points with the various organization alternatives, comparative cost relationships generally applicable throughout the requirements spectrum may be identified. This has been accomplished based on Figure B.5-1 with the result represented by the left-hand column of Figure B.5-6. Inherent in the Figure B.5-1 cost information is the assumption that "I" memories will suffice for functionally-oriented processing elements and "J" memories will be required for mission-oriented or standalone elements.* Although it is certainly true that main memory requirements for functional machines should be less than for standalone machines, it is not evident that the savings assumed for purposes of the orginal costing will actually be attained. To clearly identify the overall cost impact of the original memory size assumptions, a generally applicable cost ordering which assumes "J" memories for all processing elements has been developed. This alternative ordering appears as the right-hand column in Figure B.5-6. (A comprehensive graph analogous to Figure B.5-1 is not included herein to reflect this re-costing.)

As emphasized in Figure B.5-6 and as would be expected, the position of the standalone approach is significantly affected by the modified memory sizing assumption. This approach in particular, of course, was severely penalized by the original memory sizing. Two of the six alternatives - the TLM-TRJ and TLM-TRJ-LAUNCH approaches - maintain a reasonably favorable position in either column. (Note: The TLM-TRJ and TLM-TRJ-LAUNCH curves in Figure B.5-1 are generally separated by a constant cost of approximately $40K/mo. due only to the fact that a "J" memory was originally assigned to a launch element and to its backup element. Because subsequent investigation has indicated that assignment of an "I" memory would be more reasonable, specific cost data tabulated in subsequent material for the TLM-TRJ-LAUNCH configuration is always $40K/mo. less than indicated in Figure B.5-1. The reduced cost is often identical to that for the TLM-TRJ configuration.) Observe also that both alternatives involving a three-part functional split (TLM-TRJ-DISP and TLM-TRJ-DISP-LAUNCH) compare unfavorably with other alternatives regardless of the memory sizing assumption.

---

*An "I" memory provides main memory storage for approximately one-half million 8-bit bytes of information. A "J" memory provides storage for approximately 1 million bytes, twice as much.

WITH "I" MEMORIES FOR FUNCTIONAL MACHINES	WITH ALL MEMORIES SIZED AS "J's"
TLM-TRJ	STANDALONE
TLM-TRJ-LAUNCH	TLM-TRJ
MISSION/DISPLAY	TLM-TRJ-LAUNCH
TLM-TRJ-DISP	MISSION/DISPLAY
STANDALONE	TLM-TRJ-DISP
TLM-TRJ-DISP-LAUNCH	TLM-TRJ-DISP-LAUNCH

Figure B.5-6

SYSTEM ORGANIZATION ALTERNATIVES LISTED
IN ORDER OF GENERALLY INCREASING COST

The above leads to a straightforward conclusion: memory sizing is a very significant cost factor which must be investigated in further detail before comparative costs can be developed with confidence. Results of a preliminary investigation in this area indicate that the original memory sizing assumptions may in fact be valid. Results based on these assumptions, therefore, should be given more weight than the alternative results represented by the right-hand column in Figure B.5-6. The preliminary nature of this investigation must be emphasized, however, with the implication that a more detailed and complete memory sizing effort is warranted.

Reviewing Figure B.5-6 results for the standalone system organization in particular; it is concluded that memory sizing alone, rather than post-Apollo requirements characteristics such as an increased number of concurrent operations, suggests that a standalone system will not be economical in the post-Apollo era. Certainly increased flight density leads to increased mission overlap which in turn leads to an increased number of concurrent operations. Certainly there is some number of concurrent operations which can not be economically supported by a standalone system; this number would correspond in some sense to a cross-over point between economical employment of a standalone concept and economical employment of some functional concept. In summary, a clear-cut cross-over point dictated by requirements has not yet been reached and cost tradeoffs must be addressed at the more detailed level of engineering considerations such as memory sizing.

COST COMPARISONS FOR SPECIFIC DESIGN POINTS

Cost comparisons for specific design points are readily supported by Figure B.5-1. This section treats such comparisons for two design points of primary interest: the present Augmentation II design point, defined by the SR 500 Prime Model and associated requirements, and an alternative design point based on the most current post-Apollo program plans.

Support of the Present Augmentation II Design Point

The "present Augmentation II design point" refers to the set of post-Apollo requirements which is the basis for the MCC-H augmentation proposed by the various NASA Augmentation II working groups. This design point, specifically labeled in Figure B.5-1, involves support of the SR 500 Prime Model with the capability for four concurrent operations, two simultaneous critical phases, and dynamic standby backup for critical phases.

RTCC system costs to support the present design point are tabulated in Figure B.5-7 for each of the six alternatives of interest. Two distinct sets of comparative cost data appear to again identify the impact of different memory sizing assumptions. The three underlined organizations are of particular interest; the standalone alternative as representing the existing system concept, the TLM-TRJ-LAUNCH alternative as corresponding roughly to the system approach being proposed by the NASA Data Handling Working Group, and the TLM-TRJ alternative as being the least expensive. Cost differentials or "Δ's" are specifically indicated between the TLM-TRJ and the TLM-TRJ-LAUNCH alternatives. These two approaches are viewed as the major contenders at this design point. (The TLM-TRJ-DISP configuration would always be eliminated in favor of the less expensive TLM-TRJ approach; the former has no advantages over the latter and, in particular, has none of the potential non-cost advantages of the TLM-TRJ-LAUNCH configuration.)

	WITH "I" MEMORIES FOR FUNCTIONAL MACHINES		WITH ALL MEMORIES SIZED AS "J's"		
	TLM-TRJ	\$489K/mo.*	TLM-TRJ	\$589K/mo.	
$\Delta \cong$ 50K	TLM-TRJ-DISP	522	TLM-TRJ-DISP	642	Δ 7
	TLM-TRJ-LAUNCH	540	TLM-TRJ-LAUNCH	660	
	TLM-TRJ-DISP-LAUNCH	742	STANDALONE	770	
	MISSION/DISPLAY	747	TLM-TRJ-DISP-LAUNCH	862	
	STANDALONE	770	MISSION/DISPLAY	927	

*All costs reflect hardware rental only.

Figure B.5-7

COMPARATIVE COSTS FOR SUPPORT OF THE
PRESENT AUGMENTATION II DESIGN POINT

Conclusions drawn from Figure B.5-7 are as follows:

> The standalone system compares unfavorably with other alternatives for support of the present design point, independent of the assumptions regarding memory sizing.
>
> The TLM-TRJ configuration provides the least costly support for the present design point, independent of the assumptions regarding memory sizing.
>
> The TLM-TRJ-LAUNCH configuration appears to be a reasonable alternative for support of the present design point, recognizing that the advantages in terms of criteria other than cost may warrant the relatively small additional cost incurred by not adopting the TLM-TRJ approach.

Advantages advertised for the TLM-TRJ-LAUNCH case in terms other than cost are, of course, based on the treatment of launch (and possibly other mission phases) as special cases deserving mission-oriented or standalone support. Examples of such advantages are the greater software reliability incurred by supporting particularly critical activities with dedicated processing elements and program packages, the ability to develop stable software packages for standard activities such as launch, etc. No attempt is made herein to comprehensively evaluate these potential advantages. It should be stated, however, that certain advantages which appear convincing on the surface appear less so when pursued in more detail. For example, is it feasible to develop a stable launch package which includes pad support capabilities for EM monitoring? No judgment is intended, but caution is suggested. The conclusion reached above concerning the TLM-TRJ-LAUNCH configuration is, therefore, based less on a firm commitment to non-cost advantages and more on the observation that the cost penalty is slight in light of the "ball-park" character of all cost results.

Support of an Alternative Design Point

Two reasons may be found for considering design points other than the one presently being pursued for Augmentation II purposes. First, a better definition of post-Apollo program plans has been achieved since the time the SR 500 Prime Model was formulated. Second, the Prime Model is characterized by a degree of mission and flight overlap which results in a somewhat conservative, or even unrealistic, statement of total computer hour requirements. (See previous discussion.) These reasons imply that realism and consistency with the most current flight planning are criteria for selection of a set of requirements to be supported. Selection of a design point is not trivial; this process should be given careful attention.

Based on the criteria implied above, an alternative design point has been constructed by combining the presently funded earth orbit flights 209-212 with a lunar flight complement from M(P)-2A. In particular, flights 209-212 have been "overlaid" on the M(P)-2A time-line commencing in April 1968. A description of earth orbit activity for the total duration of the M(P)-2A schedule has been achieved by repeating the 209-212 flight complement at regular intervals whose duration is equal to the spacing between 209/210 and 211/212. (Because present plans describe this spacing as a variable somewhere in the three to six month range, an average spacing of 4.5 months is assumed.) Having formulated a revised M(P)-2A flight schedule in this manner, preliminary analyses have been conducted to determine flight density, vehicle support requirements, and direct support computer hour requirements. In addition, launch intervals have been investigated to estimate the number of concurrent operations required within the MCC-H.

Analyses of the alternative design point conclude that this point, defined as above, corresponds roughly to the following existing point within the requirements spectrum: support of M(P)-2A, average density, with three concurrent operations, two simultaneous critical phases and dynamic standby backup for critical phases. This particular set of requirements is specifically labeled in Figure B.5-1. Actually, the specification of two simultaneous critical phases and of dynamic standby backup for critical phases is somewhat arbitrary and should be evaluated carefully in a more thorough consideration of possible alternative design points.

Comparative costs for support of this new design point have been considered only for the memory sizing assumptions inherent in the original costing of alternatives; as discussed previously, preliminary investigation supports the validity of these assumptions. Because the formulation of the alternative design point must in itself be considered preliminary, specific cost tabulations have not been prepared. It may be simply concluded, however, that the TLM-TRJ-LAUNCH alternative provides the least expensive support for the alternative point of interest. (Actually, same cost as TLM-TRJ alternative when launch element memory sized as "I".) For this alternative, costs additive to those associated with supporting the Prime Model are incurred only by the addition of a Model 50I to accommodate additional computer hour demands.

Sensitivity Considerations

Because these considerations of alternative design points are somewhat preliminary, the conclusions reached above are not definitive in terms of clearly suggesting a course of action. The above conclusions are particularly significant, however, as indicating the extent to which the economies of the TLM-TRJ-LAUNCH configuration are sensitive to choice of a particular design point. More specifically, the fact that TLM-TRJ-LAUNCH configuration costs compare favorably at both the original and the new design point verifies that this alternative, viewed as an organizational scheme, provides reasonable support for different portions of the requirements spectrum. Furthermore, the addition of only a Model 50 to account for the changes in requirements indicates that from a machine complement viewpoint, as well as from an organizational scheme viewpoint, the TLM-TRJ-LAUNCH configuration is relatively insensitive to choice of a design point. Note that such sensitivity considerations constitute a valid basis for evaluating the merits of a particular organization alternative in terms both of organizational characteristics and of the specific machine complement. (Note also that if design results are particularly sensitive to changes from a given design point, one might question the merits of the design point itself as well as the merits of the design results in support of that point; a design point should not be too unique in terms of the support requirements it demands.)

ACR AND GSSC CONSIDERATIONS

The design results previously developed do not reflect ACR or GSSC requirements; such results pertain only to the post-Apollo equivalent of the present RTCC configuration. This section addresses the impact of ACR and GSSC requirements on the RTCC computing resources devoted to post-Apollo support.

The ACR and GSSC systems have been considered somewhat differently when evaluating their impact on the RTCC. They are considered together, however, because they are viewed as exerting opposing pressures on the RTCC with the net increase in requirements being of ultimate interest. In particular, integration of the ACR with the RTCC will clearly impose additional requirements on the RTCC. GSSC capabilities, on the other hand, might relieve the RTCC of a portion of its computer hour burden if use is made of any GSSC computer time not required for simulation purposes. The approach adopted herein is specifically oriented toward estimating GSSC and ACR impact on the RTCC in terms of computer hour requirements which were <u>not</u> reflected during the original development of design results. The term "net" was used previously because additional computer hour requirements have been calculated as follows:

> Net additive computer hour requirements = ACR computer hour requirements minus available GSSC computer hours which can be used to support RTCC job shop activities.

This formulation implies that the utilization of GSSC hours for RTCC job shop work will release computer hours in the RTCC which can then be devoted to satisfying ACR requirements.

In support of the approach described, Appendix A.4 estimators may be directly employed to estimate GSSC computer hour requirements as a function of flight density. Any unused computer time may then be calculated by subtracting the requirements derived from Appendix A.4 from the computer time available within the GSSC, the latter being determined by the number and type of GSSC machines. In summary, therefore, unused GSSC hours may be readily calculated once the GSSC configuration is known.

A significant problem develops, however, when attempting to quantify ACR computer hour requirements in support of the above approach. As discussed in more detail in Appendix A.4, ACR computer hour requirements are extremely sensitive to the form of integration with the RTCC. They are also sensitive to factors such as the degree to which ACR and RTCC functions continue to be redundant and the level to which ACR programs are developed before being integrated with the RTCC. All such statements point to the fact that an ability to reliably estimate ACR computer hour requirements is precluded by a lack of clear groundrules and explicit philosophy concerning ACR/RTCC integration. All that can be accomplished at this point, then, is the development of an example which illustrates the general range of net computer hour requirements and the magnitude of their impact on the design results previously developed.

Sample calculations are made for two cases involving support of the present Augmentation II design point with a six machine TLM-TRJ-LAUNCH system. The first example assumes job shop integration of the ACR with the RTCC as defined in Appendix A.4; this form of integration appears to be reasonable in terms of the efficiencies incurred while preserving the advantages of a loose software coupling between ACR and RTCC functions (assuming such advantages to be applicable in the post-Apollo era). The specific computer hour requirements used are based on the case developed in Appendix A.4 which assumes a 360/75 to be 50% busy performing ACR calculations during mission and simulation time. Two 360/75's are postulated as the GSSC configuration selected to provide a dual simulation capability, noting that useful computer time is estimated as 525 hours per month per machine. Calculations for this first example are as follows:

$$\text{NET} = \text{ACR Requirements} - \text{Available GSSC Hours}$$

$$= 431 - [(2 \times 525) - 417]$$

$$< 0$$

Conclusion: No additions are required to the six machine complement represented by the original design results.

The second example differs from the first in two important respects. First, loose integration of the ACR with the RTCC is assumed (see Appendix A.4). Second, no computer hours are assumed to be available within the GSSC. To partially offset the loss of any available GSSC hours, the calculations illustrated below take advantage of 308 unused hours within the original six machine complement. (This figure was obtained by returning to the detailed consideration of computer hour requirements which led to the six machine result. This factor was not introduced in the first example because the net requirement was less than zero.) Calculations follow:

$$\begin{aligned} \text{NET} &= \text{ACR Requirement} - \text{Available GSSC Hours} \\ &= 719 - 0 \\ &= 719 \end{aligned}$$

Taking advantage of the unused hours within the six machine configuration,

$$\begin{aligned} \text{Reduced NET} &= 719 - 308 \\ &= 411 \end{aligned}$$

Conclusion: The addition of a single 360/75 is required.

The implications of the above on final determination of a specific machine complement, assuming support of the present design point with a TLM-TRJ-LAUNCH configuration, are as follows:

The original six machine configuration will adequately support the combination of ACR and RTCC requirements under certain conditions.

It appears that no more than seven machines are required to support the combination of ACR and RTCC requirements. (Admittedly, this conclusion could be invalidated once ACR computer hour requirements may be derived in a more reliable fashion.)

It is intended that this same approach be applied to any particular case of interest. Application to all previous design results throughout the requirements spectrum, however, is undesirable in that the summary result would represent an indistinguishable mix of factors associated with widely differing degrees of confidence. Other requirements viewed in terms of computer hours would be approached in the same manner as the ACR. Examples are "computerized tools" and off-line reduction and/or analysis of experiments data within the RTCC during mission time. Requirements in these areas are not yet defined in a way permitting quantitative estimates.

INTERPRETATION OF RESULTS

This section serves as a catch-all for any commentary considered pertinent to the interpretation of the design results described in the preceding material. Items of concern include the extent to which design results may be deemed conservative, any limitations implied by the level of design detail and any significant areas not yet directly addressed.

Computer Hour Estimators

A previous section, "Factors Influencing the Matrix Results," concerned itself with significant factors related to the application of computer hour as well as loading estimators. This paragraph, on the other hand, treats characteristics of the computer hour estimators themselves which are pertinent to a meaningful interpretation of design results. Because computer hour requirements greatly influence system cost, several points concerning the associated estimators deserve repetition, noting that more detailed discussions are found in Appendix A.4 and/or B.4:

> Computer hour requirements were estimated by equating a post-Apollo flight to a Gemini (or early Apollo) mission which may itself have involved more than one flight. Implication: estimated computer hour requirements are considered conservative in this sense.
>
> Computer hour requirements were estimated without taking advantage of the ability to employ multijobbing during program development and checkout (block time operations). Implication: estimated computer hour requirements are conservative in this sense. (An estimate of multijobbing payoff indicates a savings of approximately one computer's worth of time for the densities represented by the requirements spectrum. See Appendix A.4.)
>
> Program development and checkout computer time requirements were considered equal for functional and standalone configurations. Although smaller program packages in a functional system might demand fewer hours of subsystem and system testing, each "clock hour" of system testing requires one computer hour on each functional element in the system. These factors, therefore, were considered to result in no net gain or loss. Implication: as perhaps is appropriate when dealing with a system organization with which no experience has been gained, computer hour estimates reflect

program development and checkout requirements which may be conservative for functional systems.

Computer time requirements for pad support, simulations and simulation checkouts were considered equal for functional and standalone systems despite the fact that more computer hours will generally be required for functional support due to the necessity to employ more than one computing element per activity. Implication: computer hour estimates reflect such support demands in a manner which favors functional organizations. (This observation tends to rapidly diminish any concern about being too conservative in estimating program development requirements for functional systems.)

Next Level Issues

The design results previously described address the RTCC design approach question at a relatively gross level. Although this level is considered to provide adequate support for selection of a system organization alternative, the limitations implied by this level of detail are important to proper interpretation of the design results. In particular, several issues clearly warrant an attack at a more detailed level both to address significant concerns not satisfied by the present level of design and to develop confidence in the ability to economically implement the selected approach. First order issues appear to include the following:

Sizing of main memory. (Need previously identified.)

Impact of any peaking of computer hour demands on the system caused by the flight schedule.

Investigation of processing efficiencies vs. maintenance and development costs associated with tailoring RTOS for the benefit of functional machines.

Extent of inter-machine communication implied by a functional organization and the associated implications in terms of configuration control, software complexity and requirements for shared storage.

Factors affecting the required lead time for submission of program requirements and possible reductions of this lead time.

Limited Support and Experiment Data Handling Implications

The post-Apollo concepts of "limited support" and on-line support for experiment operations both invite similar design questions. Resolution of these questions, however, requires a clear definition of these concepts and the implied degree and character of MCC-H support. Because definition of these concepts does not yet permit meaningful treatment from a design viewpoint, limited support and on-line experiment data handling requirements are reflected only to the extent that loading estimates reflect EM telemetry monitoring and assume periodic monitoring of vehicles in the "limited support" category. A more comprehensive treatment has not been attempted. For example, one could consider the possibility of on-line experiment data reduction and analysis tools with the attendant "price" in terms of increased loading and program complexity. To insure the adequate coverage of limited support and experiment support requirements, it is recommended that clear groundrules be established which define the processing functions to be performed in an on-line manner and then that system organization considerations be made, recognizing that the use of a large machine such as a 360/75 may not be desirable. Regarding the latter point, note that the design results often call for equipping of model 50's with real-time interface capabilities, thereby permitting Model 50 usage for program development. So equipped, Model 50's become a promising candidate for limited support or experiment monitoring activities.

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

The more significant conclusions and recommendations are summarized below as a simple tabulation.

Conclusions

Conclusions of a general nature are as follows:

Significant RTCC cost differences are associated with supporting the different versions of post-Apollo program plans represented by the SR 500 models and the reference planning schedules.

Computer hour demands, as derived primarily from flight density requirements, are the most significant factor influencing RTCC system costs.

In the Augmentation II environment, main memory sizing greatly influences the relative cost advantages between different RTCC system organization alternatives.

In the Augmentation II environment, clear-cut cross-over points do not exist between economical use of the standalone concept and economical use of a functional concept for RTCC organization.

Reliable estimation of ACR requirements and their impact upon the RTCC, assuming integration, is precluded by the lack of groundrules defining the form of ACR/RTCC integration.

Conclusions of a more specific nature are:

Throughout the range of post-Apollo requirements, costs for a TLM-TRJ-LAUNCH system are essentially equal to costs for a TLM-TRJ configuration. Advantages in terms other than cost, therefore, are decisive. Note that the cost merits of these two alternatives are not extremely sensitive to choice of a particular design point in the spectrum of requirements.

The TLM-TRJ and TLM-TRJ-LAUNCH systems constitute reasonably attractive RTCC alternatives for support of the SR 500 Prime Model and associated requirements, the present Augmentation II design point.

A TLM-TRJ-LAUNCH system supporting the present design point involves six 360/75's with "I" memories if ACR requirements are not included. Inclusion of ACR requirements appears to dictate at most the addition of a single 360/75, resulting in a seven machine configuration.

The TLM-TRJ and TLM-TRJ-LAUNCH systems provide the least costly support of an alternative design point based on earth orbit flights 209-212 and a lunar complement from M(P)-2A.

Recommendations

It is recommended -

That design points other than that defined by the SR 500 Prime Model (and associated requirements) be considered.

In particular, that an alternative design point based on present plans for flights 209-212 be refined further than accomplished herein, the objective being to locate this point in the requirements spectrum and to identify comparative costs accordingly.

That the TLM-TRJ-LAUNCH and TLM-TRJ alternatives be comparatively evaluated in terms other than cost while parallel attempts are made to develop more definitive sizing data in the ACR area.

That the form of ACR/RTCC integration be defined and agreed to by all interested parties, thereby permitting a meaningful treatment of ACR impact on the RTCC.

That, based on the economies of a Model 50 from a computer hour viewpoint, a Model 50 be studied as a candidate for providing limited support and experiments monitoring capability without requiring that larger machines be on-line for such operations.

APPENDIX C

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Approved for Project Distribution:

W B Woodward
W. B. Woodward
Project Leader